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A STUDY OF CLOUD MOTIONS ON MARS

FINAL REPORT, PART B

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ABSTRACT

A search of 5,000 Mars plates in the Lowell Observatory collection yielded 28 groups of plates on which the local positions of well-defined bright clouds or cloud groups could be followed on a daily basis. These groups of plates were from fifteen different oppositions of Mars, starting from 1907 and ending with 1958. Each group of plates covered a time period of at least two days and up to 29 days. The position and extent of all associated clouds (whether appearing to show motion or not) were plotted on Mercator projections with the help of a projection plate reader especially designed for planet image studies of this kind.

The 28 groups of plates yielded 95 cloud histories. More than half appeared to be relatively stationary and sometimes recurrent. Others show definite motion well in excess of observational errors, but sometimes follow paths that partly double back upon themselves. The mean velocity for non-stationary clouds was found to be 5.6 kilometers per hour, and the most commonly occurring direction was eastward, particularly at high latitudes. A comparison with earlier work leads us to believe that most of the previous observations of Martian cloud motions are spurious.

Although we have used the traditional term "cloud" to describe the bright transient patches to which this study pertains, we do not attempt to say whether they are truly clouds of suspended particles or are transient local brightenings of the surface. Our distinction between stationary and non-stationary clouds should not be construed as resolving this question.

INTRODUCTION

The Lowell Observatory collection of Mars photographs includes about 5,000 plates taken through various color filters since the turn of the century. These plates were taken at Lowell Observatory in Flagstaff and also during Lowell expeditions to Chile and South Africa. The collection was searched for distinct bright clouds whose positions and positional changes could be followed from day to day over a period of time. Twenty-eight suitable groups of plates were found. These were from fifteen different oppositions of Mars, starting with 1907 and ending with 1958. Each group of plates covered a time period of at least two days and up to twenty-nine days.

The study was limited to the smaller and more discrete types of clouds, since those covering broader areas are more difficult to map to the accuracy needed for comparing the positions and configurations seen on various plates. The study was also limited to clouds well within the visible disk so as to maintain a high order of accuracy. Limb clouds and polar clouds were avoided, because the appearance of rapid changes in those regions may be deceptive.

For the purposes of this study the term "cloud" is applied to any distinctively bright Martian area which is not a normal tone of the surface feature in that area. We do not really know whether these are truly atmospheric features or a transient lighter coloration on the surface of the planet. The lack of detectable movement suggests that at least some of them may be surface phenomena. Bright areas within Hellas and Elysium were included on several of the maps.

PROCEDURE

The first step was a plate-by-plate search for those Mars plates which had clouds that could be mapped. Small sketch maps showing the approximate configurations and locations of all clouds were made for each plate. All readable plates were included, regardless of the filter color.

The sketch maps were then reviewed to determine which plates showed clouds that might be related to clouds seen on other plates within a reasonable time span. All possible relationships were included, regardless of the motion or non-motion that appeared to be indicated.

The planetary image projector described in Part A of our final report (see especially Figures 2 and 3 of Part A) was used to map clouds from the selected groups of plates. Each projected Mars image was adjusted in size, orientation, and position to fit a transparent

coordinate graticule superimposed on the projection screen. This graticule was an orthographic projection grid with latitude and longitude lines at intervals of 10 degrees. Different orthographic graticules were used to accommodate different tilt angles of the Martian axis (in steps of 2 degrees) with respect to the line of sight.

The clouds were first outlined with a grease-pencil on a transparent plastic sheet covering the projection screen. This outline was then transferred to a Mercator projection by drawing it on a transparent plastic sheet covering a sliding Mercator graticule on top of a Mercator map of the Martian surface. The sliding Mercator graticule, with 10-degree intervals in both coordinates, was placed so that the location of its central meridian on the map corresponded with the central meridian in the photograph. Thus the Mercator projection lines corresponded with the orthographic projection lines.

Final maps were compiled from these plastic overlays. All together, there are 29 final maps, one for each of the 28 selected groups of plates, except for one case that required two maps to represent the situation completely. When several plates taken during the same day showed the same cloud in about the same position, these cloud outlines were averaged in size and position to show a single symbol for that date. Clouds which could not be related to the others were usually omitted.

CLOUD MAPS

Each of the 29 attached maps covers only a part of Mars. They are all at about the same scale, namely, 1:50,000,000 at the equator. Each includes a small bar scale which gives the scale in kilometers -- at the equator and at 20° and 40° latitude away from the equator. The maps have been oriented with north at the top and areographic east to the right. Longitude is numbered from 0° to 360° in a westerly direction. Since we used Mercator projections, azimuths may be drawn as straight lines.

The base map of the Martian surface is taken from the NASA-Air Force chart "Mariner 69 Mars Chart (MEC-2)" drawn at Lowell Observatory. The projection lines at 10-degree intervals have been included from this map, but feature names have been omitted.

Each cloud symbol on the maps is listed below the map, together with the date of the photographs on which it appeared. The listing also includes the number and color of the photographs associated with each symbol. On days for which more than one symbol has been mapped, the list indicates which symbols were derived from the same (common) plates and how many plates were in common.

Each different number on a symbol represents a different Martian day in chronological order. These days are not necessarily consecutive. Gaps between dates arise, either because plates were lacking or because the available plates were not of readable quality. There was no clear-cut case of a cloud totally disappearing one day and reappearing the next.

The lower-case letters are an aid in referencing groups or clusters of symbols. The groupings of symbols and the assigning of letters to these groups have necessarily been somewhat arbitrary.

CONCLUSIONS

From an examination of the 29 attached maps, we find that there appear to be 95 usable cloud histories. This is the number gleaned from 97 mapped symbol groupings, after five cases of doubtful association were omitted and after three of the symbol groups were each split into two probable cases.

Of these 95 selected cases, 52 appear to be relatively stationary, while the remaining 43 show evidence of motion. A cloud was regarded as stationary if its mapped locations from a sequence of dates remained unchanged within the accuracy of measurement. The cloud on Map Sheet No. 1 is a good example of this stationary class. In uncertain cases, the criterion for calling a cloud "stationary" was that the first and last positions be within 400 kilometers of one another.

For the 43 clouds regarded as showing evidence of motion, velocity vectors were measured on the basis of the first and last positions. In some instances, such clouds moved first in one direction and then doubled back in the opposite direction, so that the net displacement between the first and last positions was less than the total excursion. In other cases the displacements were progressively in one direction, and the total motion was many times larger than any possible measuring error. Moreover, some of the moving clouds are found on the same sets of plates as stationary ones, so that there can be no question about the motion of one relative to the other.

There is an occasional case for which it might be debated whether the mapped positions all represent the same cloud history or whether more than one cloud was involved. In our opinion, such cases of multiple identity are unlikely among the 95 selected.

Velocities based on the first and last positions of a cloud are vulnerable to mapping errors unless the time span of observation was long enough. We decided to confine velocity analysis to 35 cases (among the total 43) for which observations spanned more than

72 hours. These 35, taken together with the 52 clouds regarded as stationary, provide a high-accuracy sample of 87 clouds that yield the histogram in Figure 1. The mean velocity for all 87 clouds is 2.25 kilometers per hour. The mean velocity for the 35 non-stationary cases alone is 5.60 kilometers per hour.

The histogram in Figure 2, which includes all 95 original cases, shows that bright Martian clouds do not occur randomly over the whole planet. Only one-fourth of them occurred in the southern hemisphere. Almost half of the clouds are found in a relatively narrow belt between the equator and 20°N latitude.

There also seems to be a partial avoidance of the darker areas on Mars. Roughly 25 percent of the Martian surface between -60° and +60° latitude can be regarded as dark area, and it was found that only eight clouds (fewer than 10 percent of the sample) substantially overlaid such areas. The latitude effect in Figure 2 could, of course, be merely a manifestation of this dark-area avoidance, because a large percentage of the dark area of Mars lies in the southern hemisphere. The avoidance of dark areas cannot be an observational selection effect, because the visibility of bright clouds will be greater--not less--over dark areas than over light areas.

Figure 3 shows that somewhat more clouds move east and west than north and south. This diagram represents the number of cases falling within each 45° sector of the compass. The sample was limited to the 35 non-stationary clouds observed for 72 hours or more. On average, those moving eastward are a little farther from the equator than those moving in other directions. The sample is not yet large enough to delineate a complete atmospheric circulation pattern. This is one of the goals of the Planetary Patrol Program.

Previous observations of Martian cloud movement were reviewed by F. A. Gifford, Jr., in the October 1964 issue of the Monthly Weather Review. Gifford tabulated 36 velocities and directions of motion that had been reported by various observers since 1873. Many were derived from visual observations, and twenty of the 36 were based on the appearance of clouds at the limb or terminator. The mean of Gifford's tabulated velocities is 36 kilometers per hour, which is more than six times larger than the mean of our values derived from more careful measurements in the present study. The highest single value in Gifford's list is 124 kilometers per hour (credited to Observatoires Jarry-Desloges), and it is more than eight times larger than the highest velocity found in the present study. The predominant direction of motion in Gifford's list is westward--just opposite to that found in our work. It appears to us that most of the earlier work must have been subject to very large observational errors that led to unrealistic results having little relation to what is actually happening on the planet.

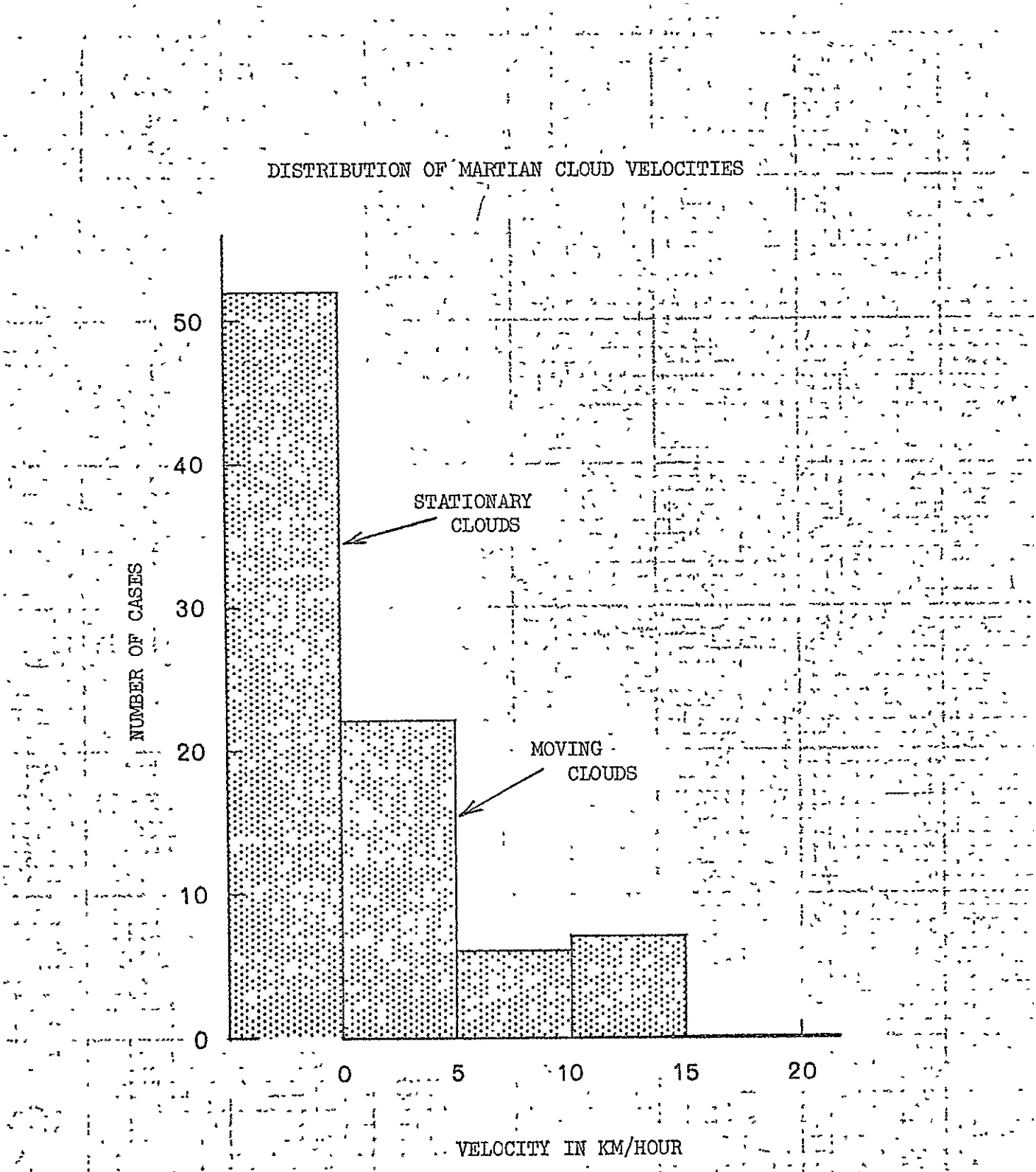

DISTRIBUTION OF MARTIAN CLOUD VELOCITIES
NUMBER OF CASES
50
40
30
20
10
0
STATIONARY CLOUDS
MOVING CLOUDS
0
5
10
15
20
VELOCITY IN KM/HOUR

Figure 1.

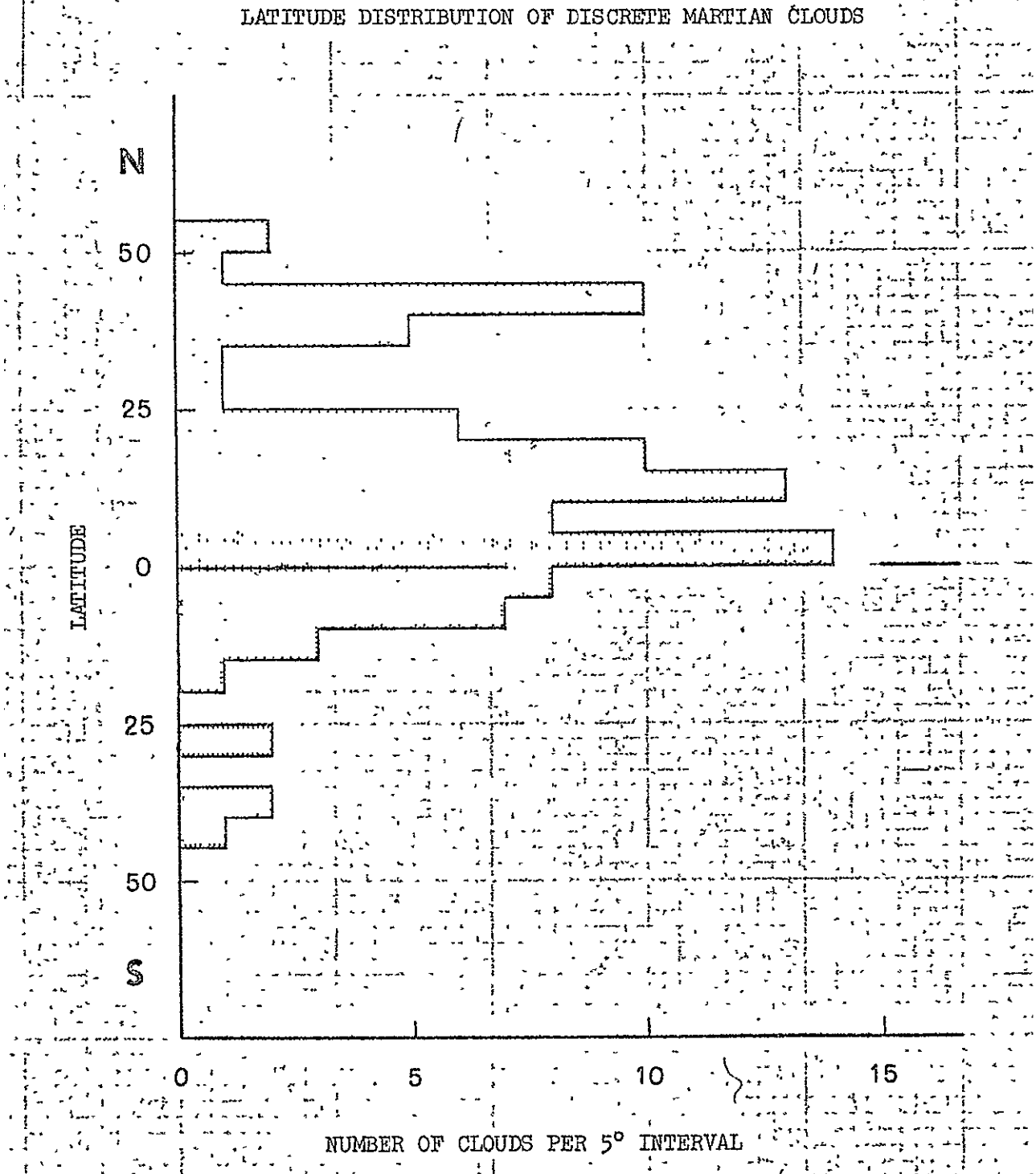

LATITUDE DISTRIBUTION OF DISCRETE MARTIAN CLOUDS
N
50
25
0
25
50
S
LATITUDE
0
5
10
15
NUMBER OF CLOUDS PER 5° INTERVAL

Figure 2.

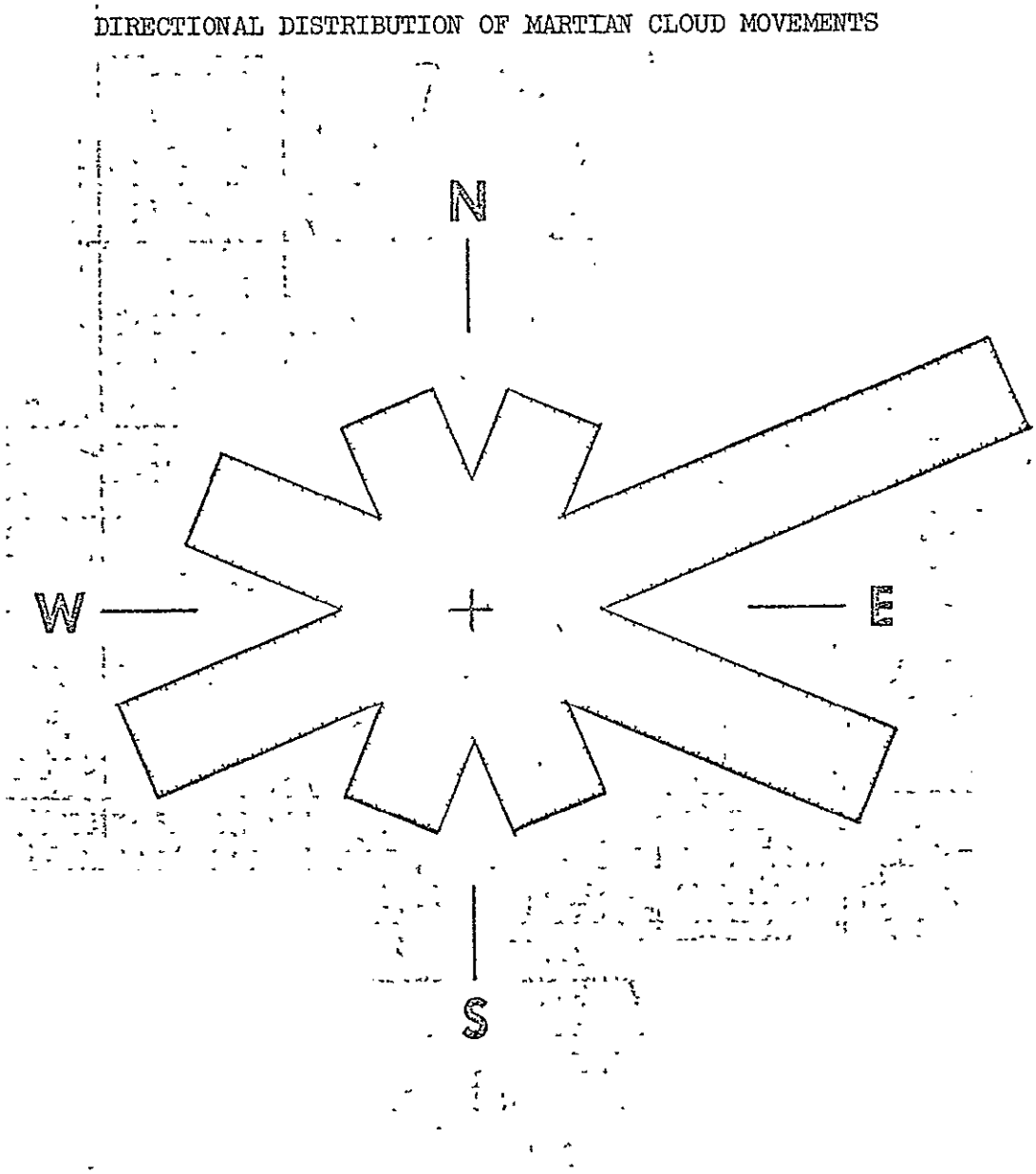
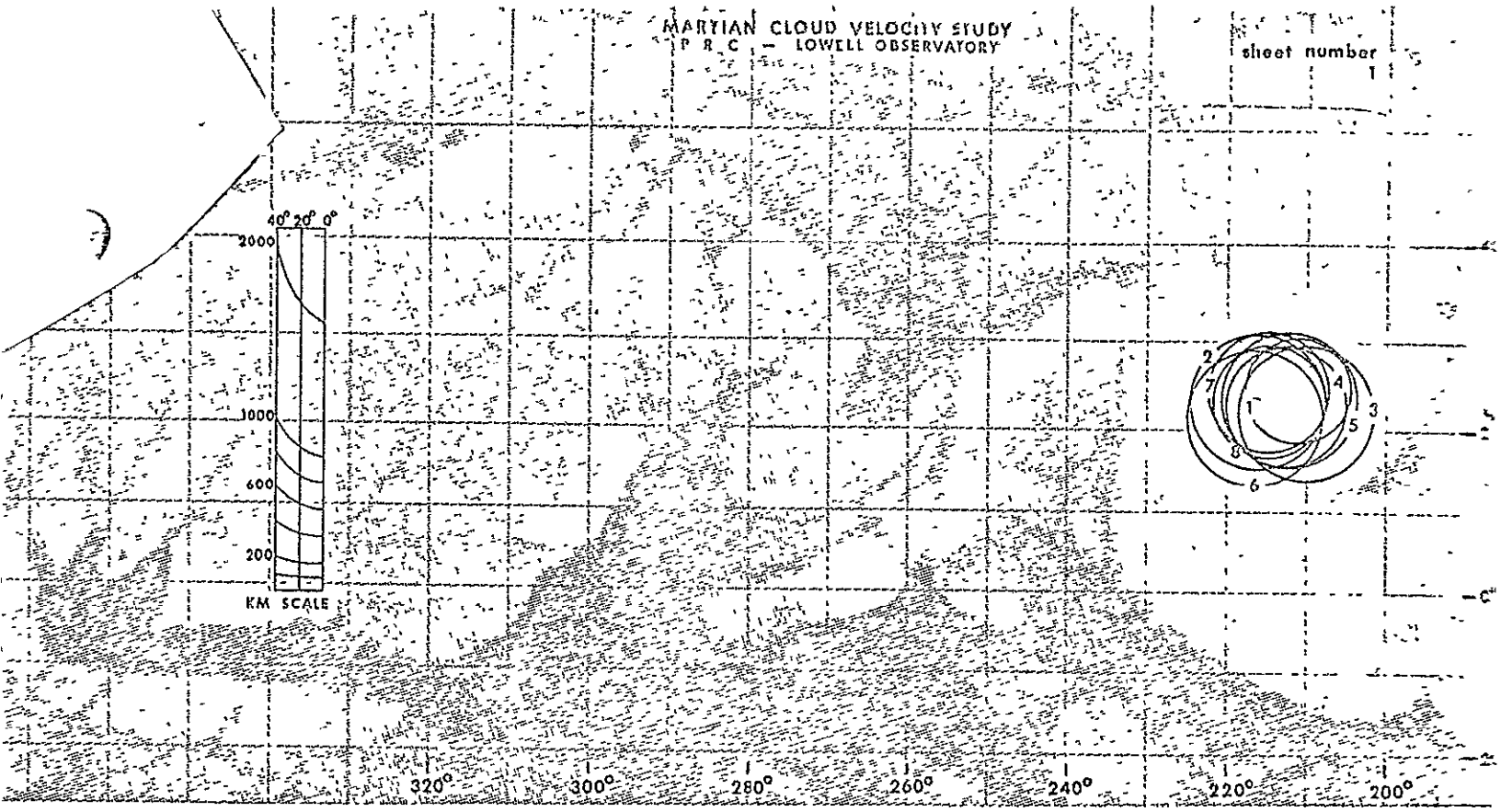


Figure 3. Diagram showing the relative numbers of bright Martian clouds moving in various directions. Each bar represents the number of cases falling within a 45-degree sector of the compass.

INDEX TO SHEETS

Sheet No.	Apparition	Areographic Locations
1	1907	200° - 320°; 20°S - 40°N
2	1907	20° - 160°; 20°S - 40°N
3	1920	200° - 320°; 20°S - 40°N
4	1920	20° - 160°; 20°S - 40°N
5	1922	320° - 80°; 40°S - 20°N
6	1924	200° - 320°; 40°S - 20°N
7	1926	20° - 160°; 20°S - 40°N
8	1926	320° - 80°; 40°S - 20°N
9	1931	20° - 160°; 20°S - 40°N
10	1935	200° - 320°; 40°S - 20°N
11	1935	60° - 200°; 0° - 40°N
12	1935	200° - 320°; 40°S - 20°N
13	1935	20° - 160°; 20°S - 40°N
14	1937	200° - 320°; 40°S - 20°N
15	1937	20° - 160°; 20°S - 40°N
16	1937	220° - 340°; 20°S - 40°N
17	1937	40° - 200°; 0° - 60°N
18	1939	20° - 160°; 20°S - 40°N
19	1939	200° - 320°; 40°S - 20°N
20	1941	100° - 220°; 60°S - 0°
21	1943	200° - 320°; 40°S - 20°N
22	1950	20° - 160°; 20°S - 40°N
23	1952	200° - 320°; 40°S - 20°N
24	1952	20° - 160°; 20°S - 40°N
25a	1954	20° - 160°; 20°S - 40°N
25b	1954	20° - 160°; 20°S - 40°N
26	1958	200° - 320°; 40°S - 20°N
27	1958	20° - 160°; 20°S - 40°N
28	1958	200° - 320°; 40°S - 20°N

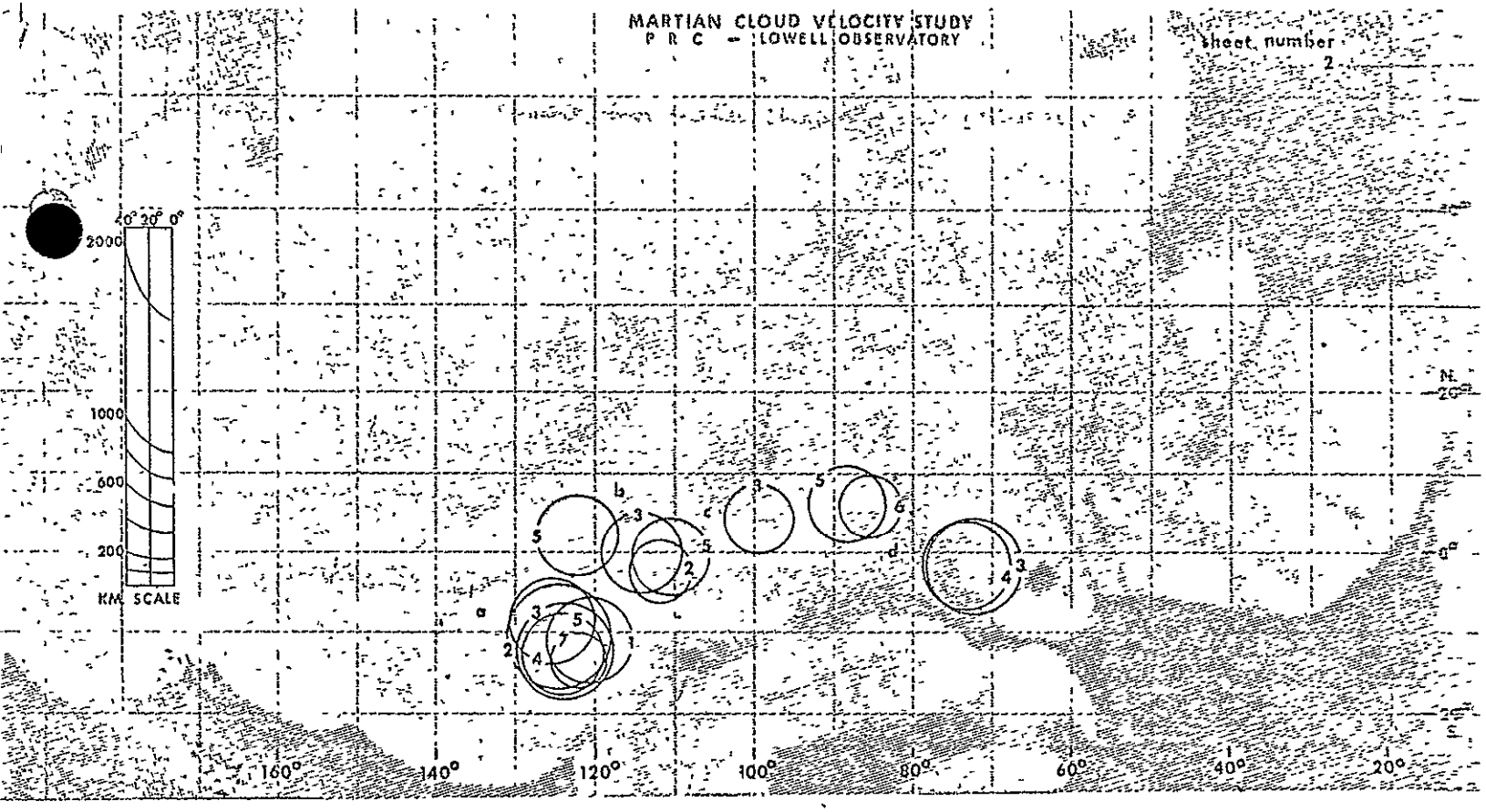


SHEET NO. 1 1907

Dates	Symbols	No. of Plates by Color
11 July	1	3 yellow
12 July	2	8 yellow
13 July	3	6 yellow
14 July	4	3 yellow
15 July	5	3 yellow
16 July	6	4 yellow
17 July	7	3 yellow, 1 red
18 July	8	2 yellow

NOTES:

The variations in positions from day to day are not large enough to be certain of movement and may indicate a non-atmospheric brightening. This is one of several examples of brightness over Elysium. Also see Sheets 3, 10, 12, 14, 16, and 23.

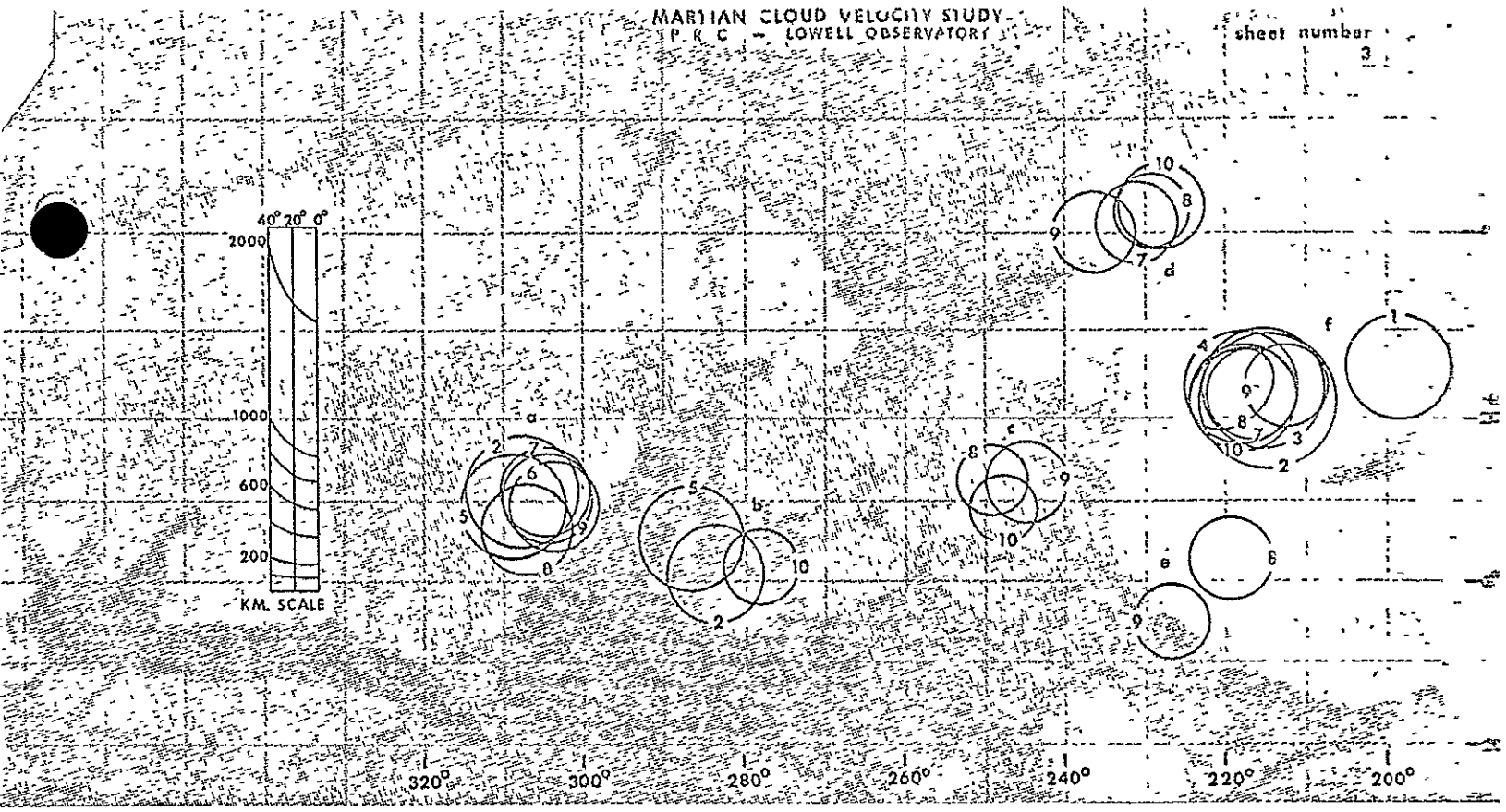


SHEET NO. 2 1907

Dates	Symbols	No. of Plates by Color
15 July	1a	3 yellow
16 July	2a	4 yellow
	2c	3 yellow (2 in common with a)
17 July	3a	2 yellow (1 in common with b)
	3b	2 yellow (1 in common with c)
	3c	2 yellow (1 in common with d)
	3d	1 yellow (in common with c only)
18 July	4a	1 yellow (not in common)
	4d	2 yellow
19 July	5a	2 yellow
	5b	1 yellow, 1 orange
	5c	2 yellow (in common with a only)
	5d	1 yellow (in common with b only)
20 July	6d	1 yellow
21 July	7a	1 yellow

NOTES:

The overlapping of groups b and c is misleading since 5b and 5c are not from common plates. Note also that 2c is closer to 3b than it is to 3c, which in turn is slightly closer to 5d than 5c. Sheet 2 overlaps Sheet 1 in time.



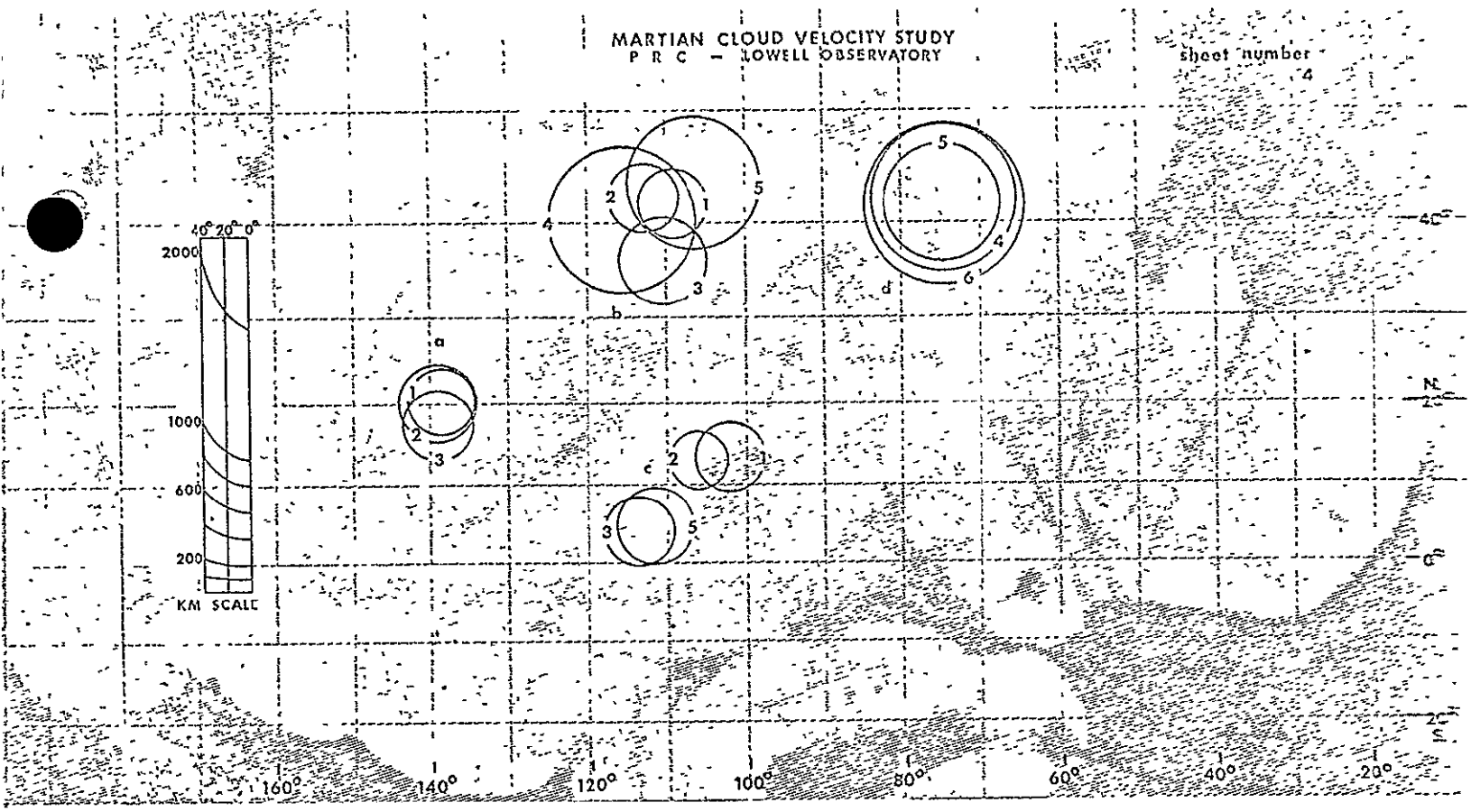
SHEET NO. 3 1920

Dates	Symbols	No. of Plates by Color
22 April	1f	1 yellow
23 April	2a	2 yellow (1 in common with f only)
	2b	1 yellow (in common with f only)
	2f	2 yellow
24 April	3f	3 yellow
4 May	4f	1 red
23 May	5a	2 yellow
	5b	1 yellow (not in common)
25 May	6a	1 yellow
26 May	7a	
	7d	1 yellow
	7f	
27 May	8a	
	8c	
	8d	1 yellow
	8e	
	8f	
28 May	9a	
	9c	
	9d	1 yellow
	9e	
	9f	

Dates	Symbols	No. of Plates by Color
29 May	10b, 10c, 10d, 10f	1 yellow

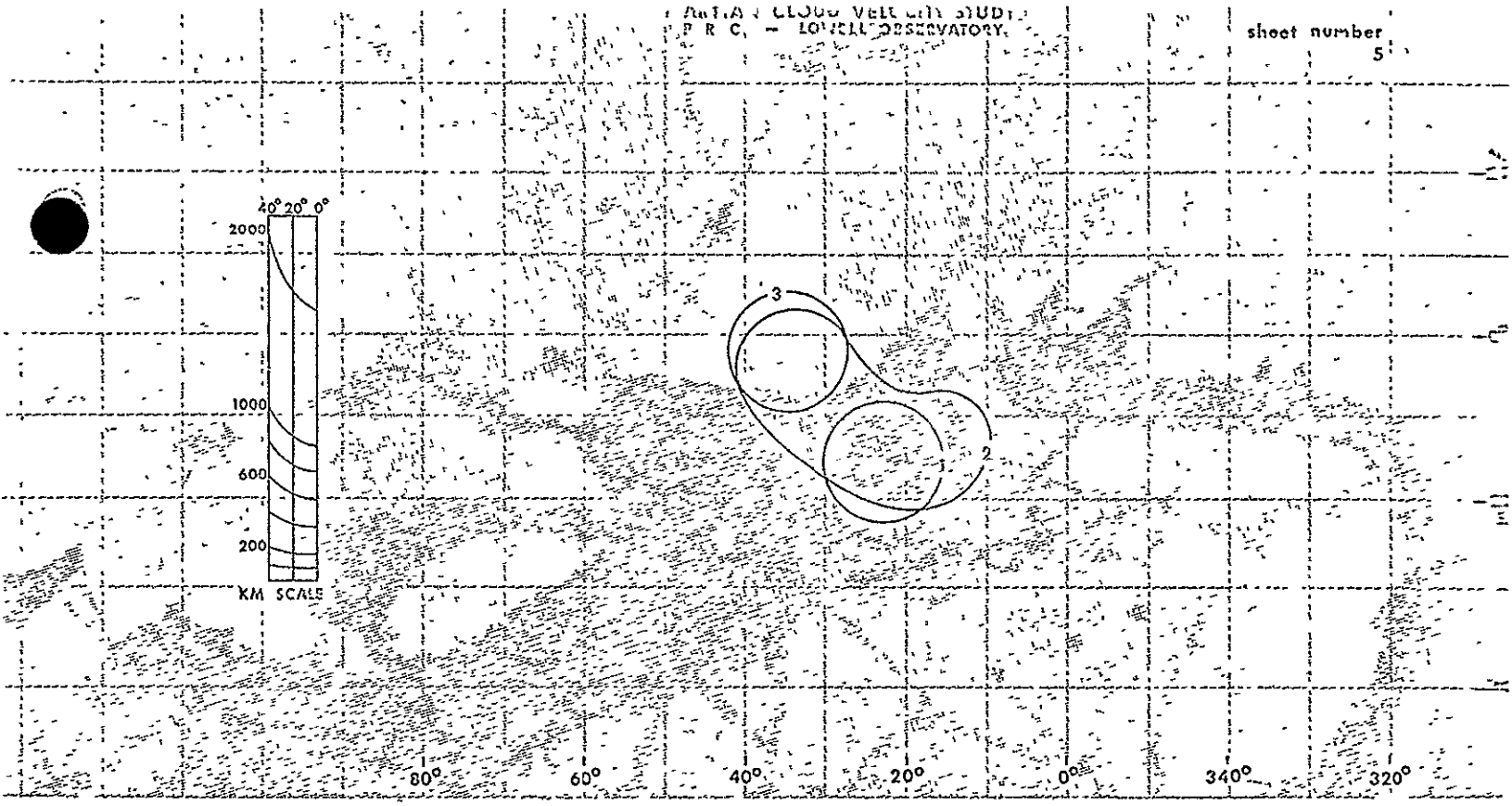
NOTES:

This sheet combines plots made from two groups of plates taken about a month apart. The groupings seem related, even with a gap of nearly three weeks in the observations. The cluster at f over Elysium is even tighter than that shown on Sheet 1. Its position is nearly the same, but centered slightly to the west. Sheet 4 falls within the time span of Sheet 3.



SHEET NO. 4 1920

Dates	Symbols	No. of Plates by Color
2 May	1a, 1b, 1c	1 yellow
4 May	2a	1 yellow, 1 red
	2b, 2c	1 yellow (in common with a)
5 May	3a, 3b, 3c	1 yellow
7 May	4b, 4d	1 yellow
8 May	5b, 5c, 5d	1 yellow
16 May	6d	2 yellow

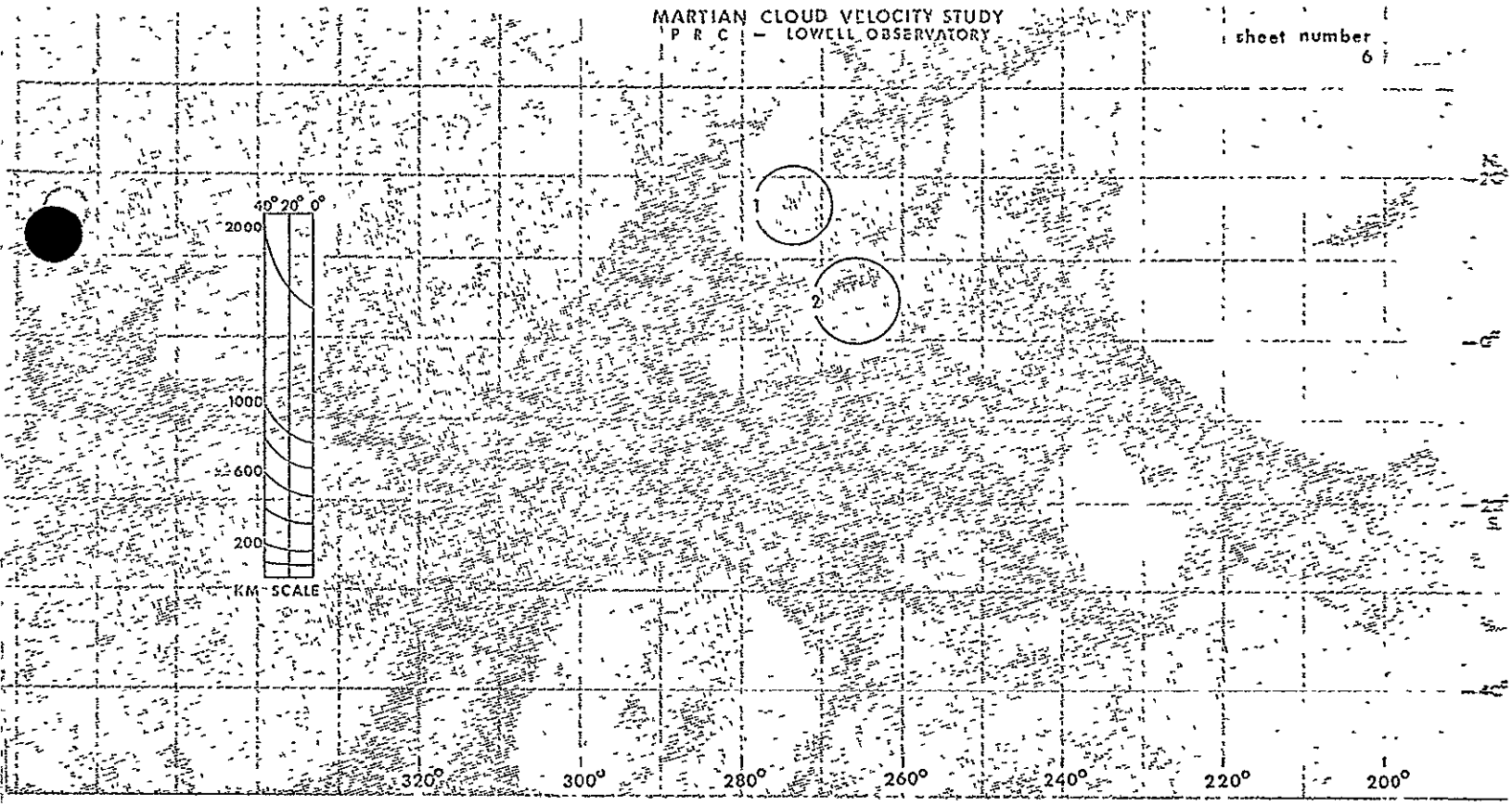


SHEET NO. 5 1922

Dates	Symbols	No. of Plates by Color
10 July	1	2 yellow
11 July	2	2 green, 1 yellow, 1 red
13 July	3	2 red

NOTES:

This sheet includes plots from three plates used by E. C. Slipher as examples of storm movement in his Mars, The Photographic Story on page 107. He selected one plate for each day. The plots from the pair of plates from the first day are in fairly good agreement, as are those from the third day. For the second day, Slipher selected the "yellow" plate. The plot from this plate was one continuous cloud, similar to symbol 2, but smaller and not extending as far north. The other three plates appeared to each show two separate clouds. One of these clouds plotted close to the same as symbol 1, and the other about the same as symbol 3. Symbol 2 as shown is a compromise between plots from all four plates.

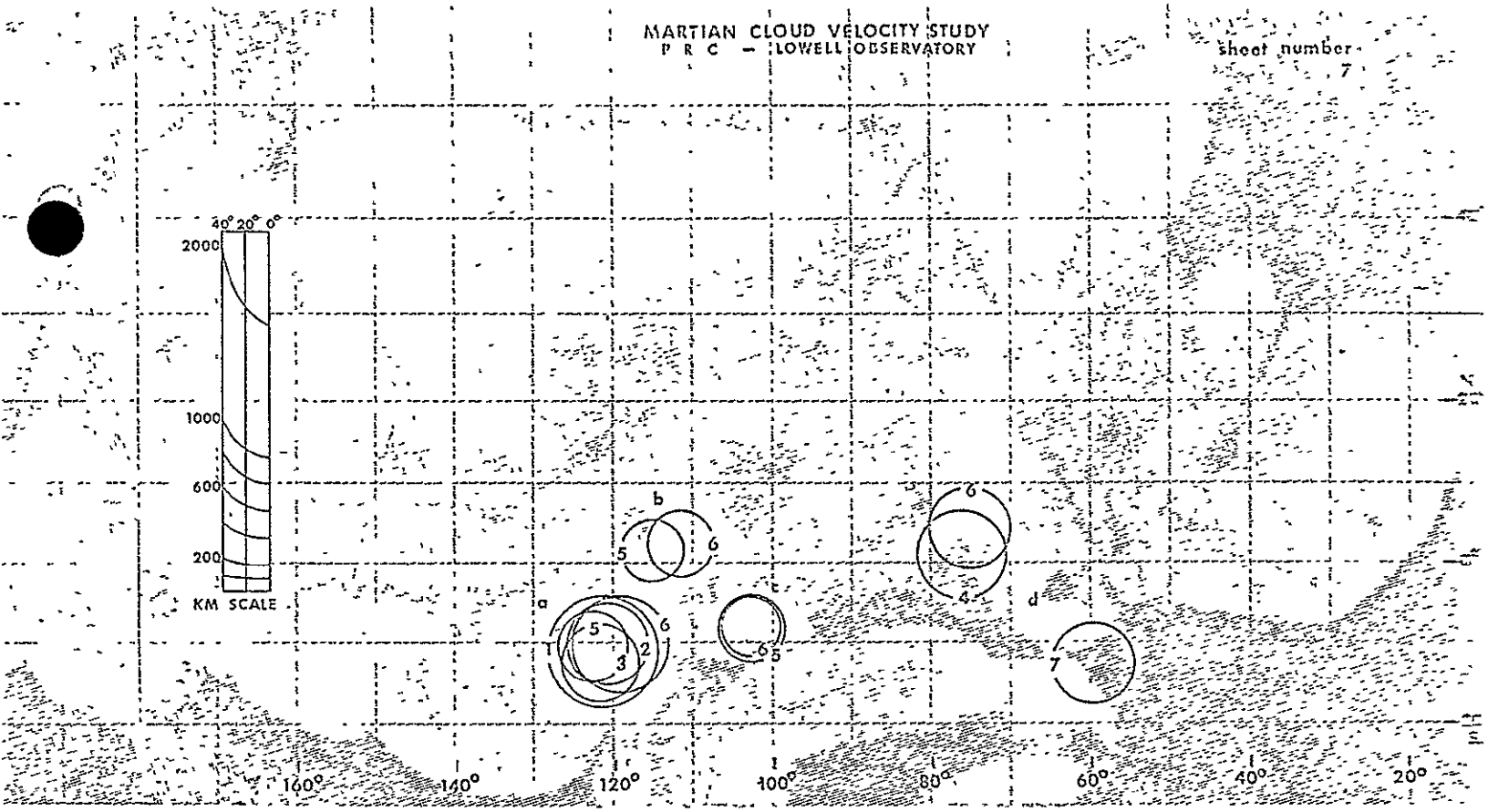


SHEET NO. 6 1924

Dates	Symbols	No. of Plates by Color
9 August	1	2 yellow, 1 red
10 August	2	5 yellow

NOTES:

Slipher used four of these plates on page 119 of his book to show cloud movement. He calculated a velocity of twenty-two miles per hour, which is a little faster than this sheet would indicate.

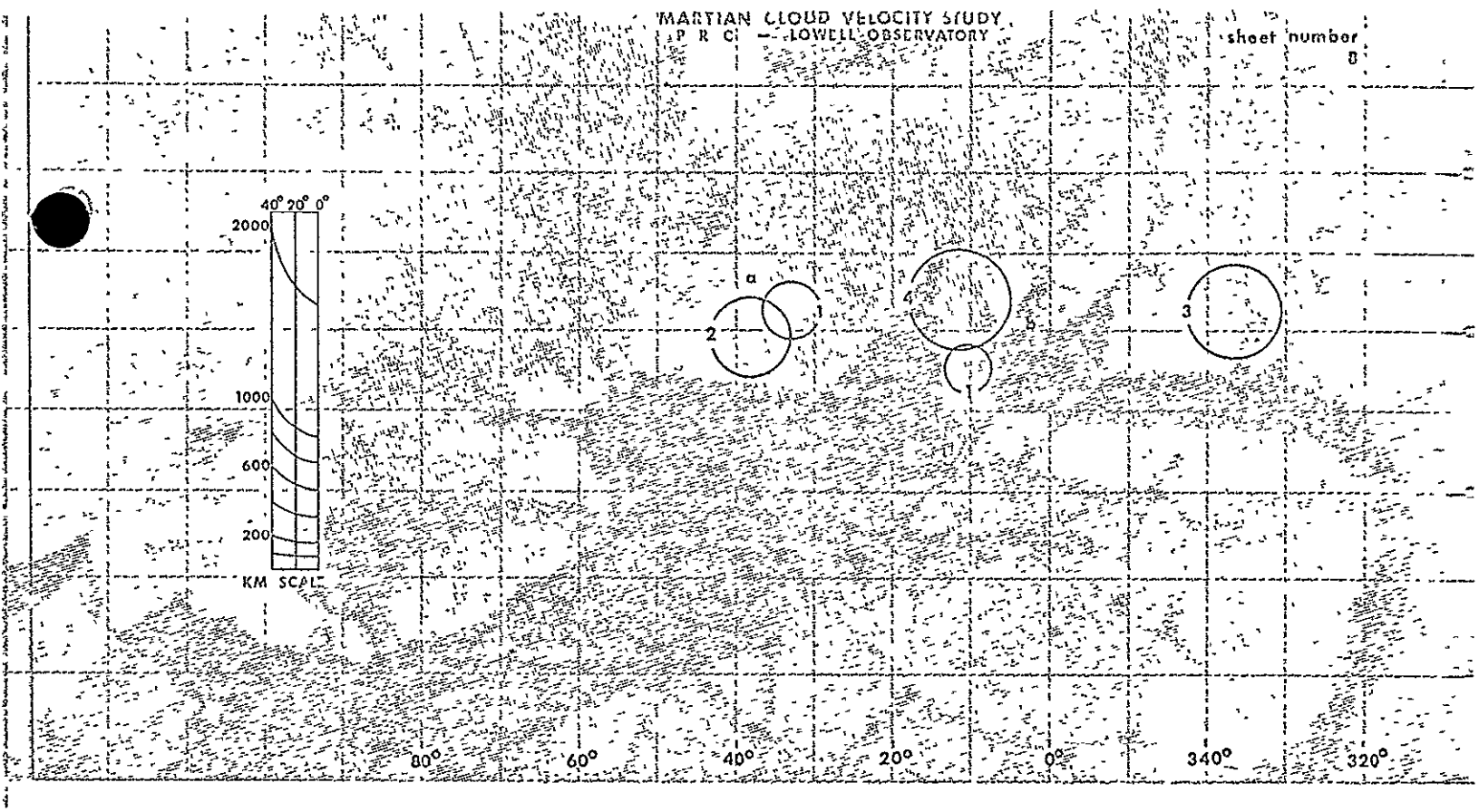


SHEET NO. 7 1926

Dates	Symbols	No. of Plates by Color
13 October	1a	5 blue
14 October	2a	4 blue
15 October	3a	1 blue
18 October	4d	2 blue
19 October	5a, 5b, 5c	2 blue
21 October	6a	1 ultraviolet, 2 blue
	6b, 6c	1 blue (in common with a only)
	6d	1 blue (in common with a only)
26 October	7d	1 blue

NOTES:

Sheet 8 overlaps 7 in both time and area, but there are no common plates.

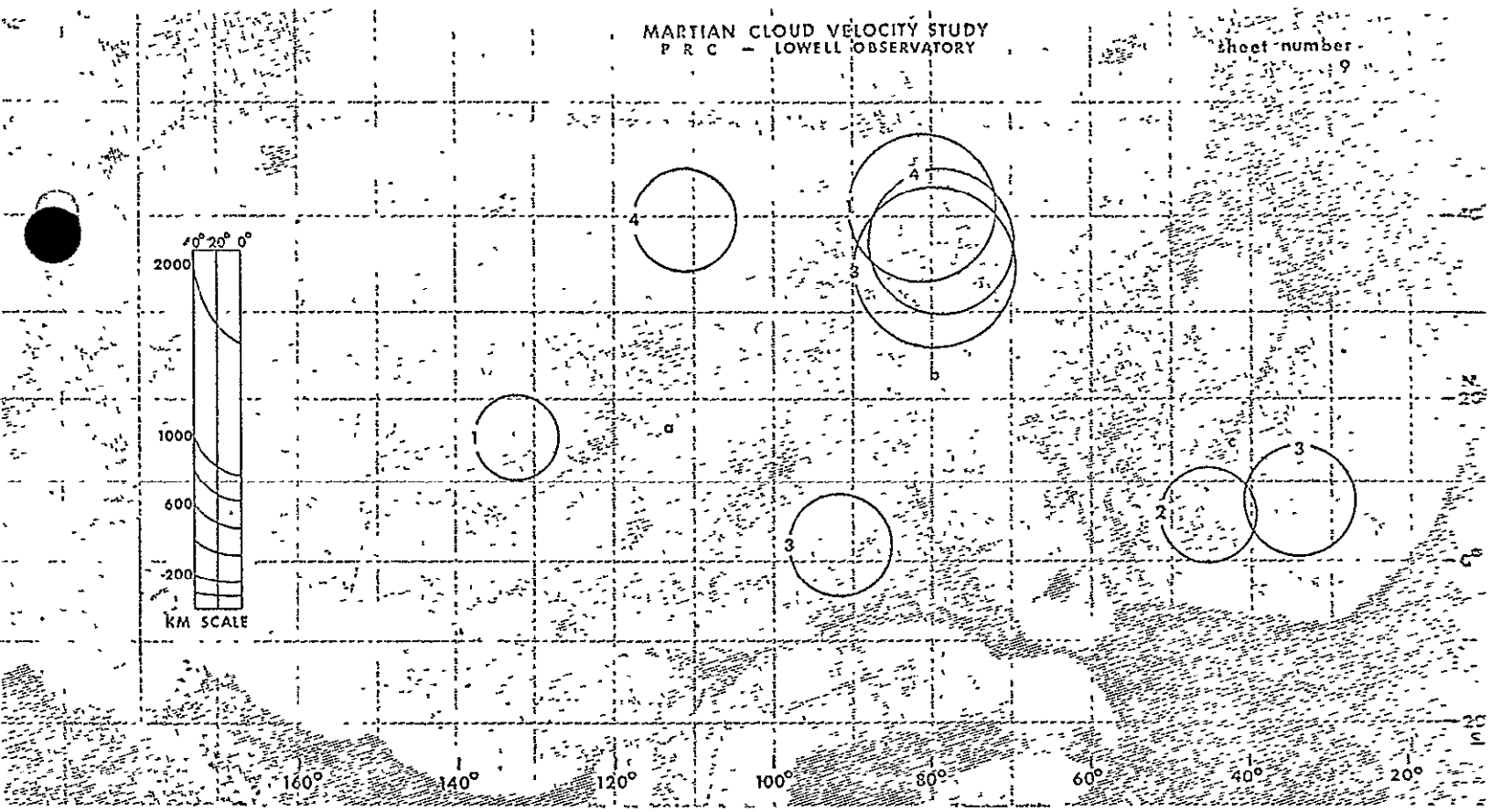


SHEET NO. 8 1926

Dates	Symbols	No. of Plates by Color
23 October	1a, 1b	1 blue
27 October	2a	1 yellow
28 October	3b	1 blue
3 November	4b	1 blue

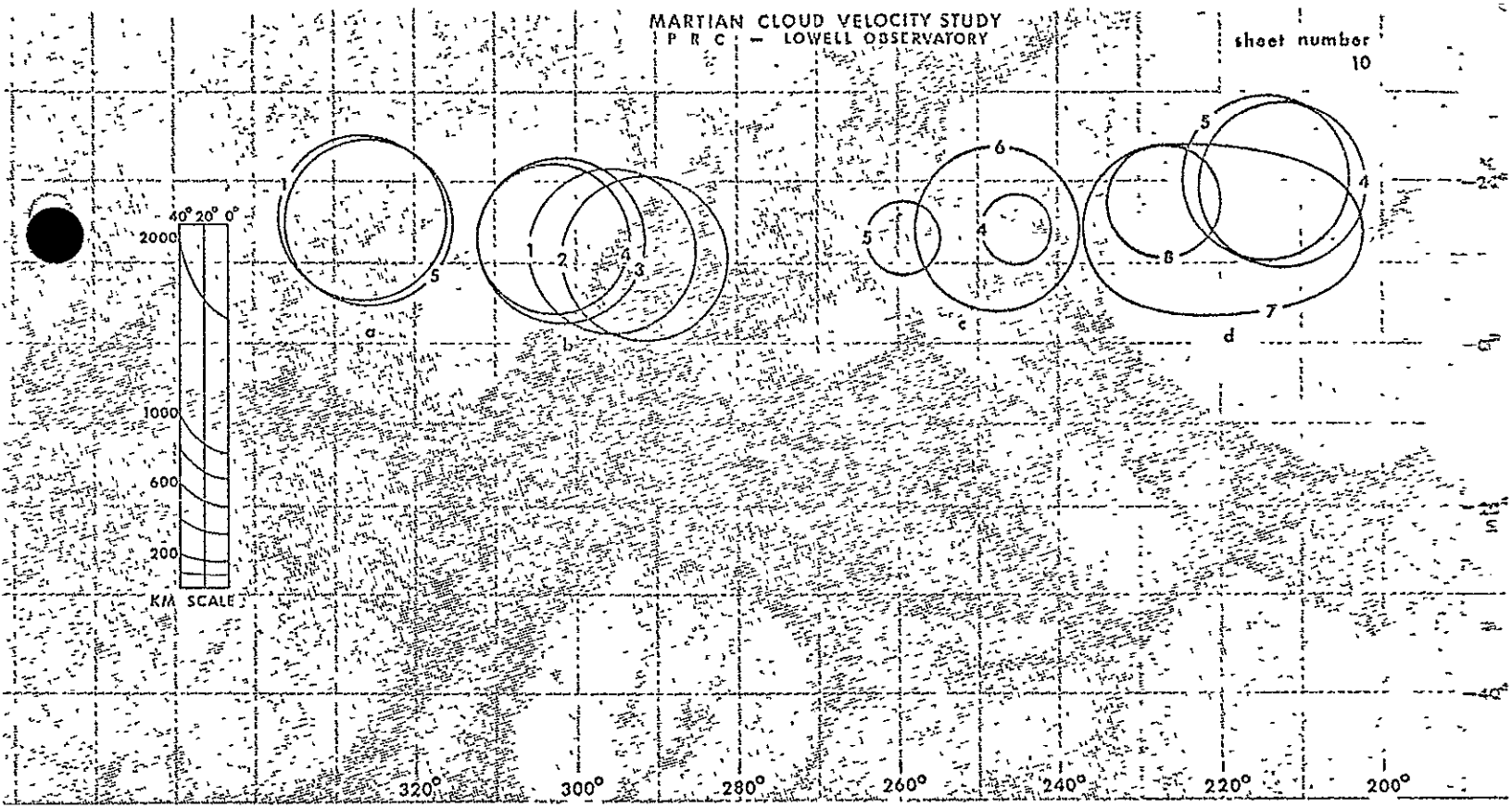
NOTES:

Sheet 7 overlaps 8 in both time and area, but they use no plates in common.



SHEET NO. 9 1931

Dates	Symbols	No. of Plates by Color
31 January	1a	1 blue
	1b	1 blue (not in common)
2 February	2c	1 blue
9 February	3a	1 yellow (in common with b)
	3b	1 blue, 2 yellow
	3c	1 blue (in common with b)
10 February	4a	1 yellow (in common with b)
	4b	2 yellow

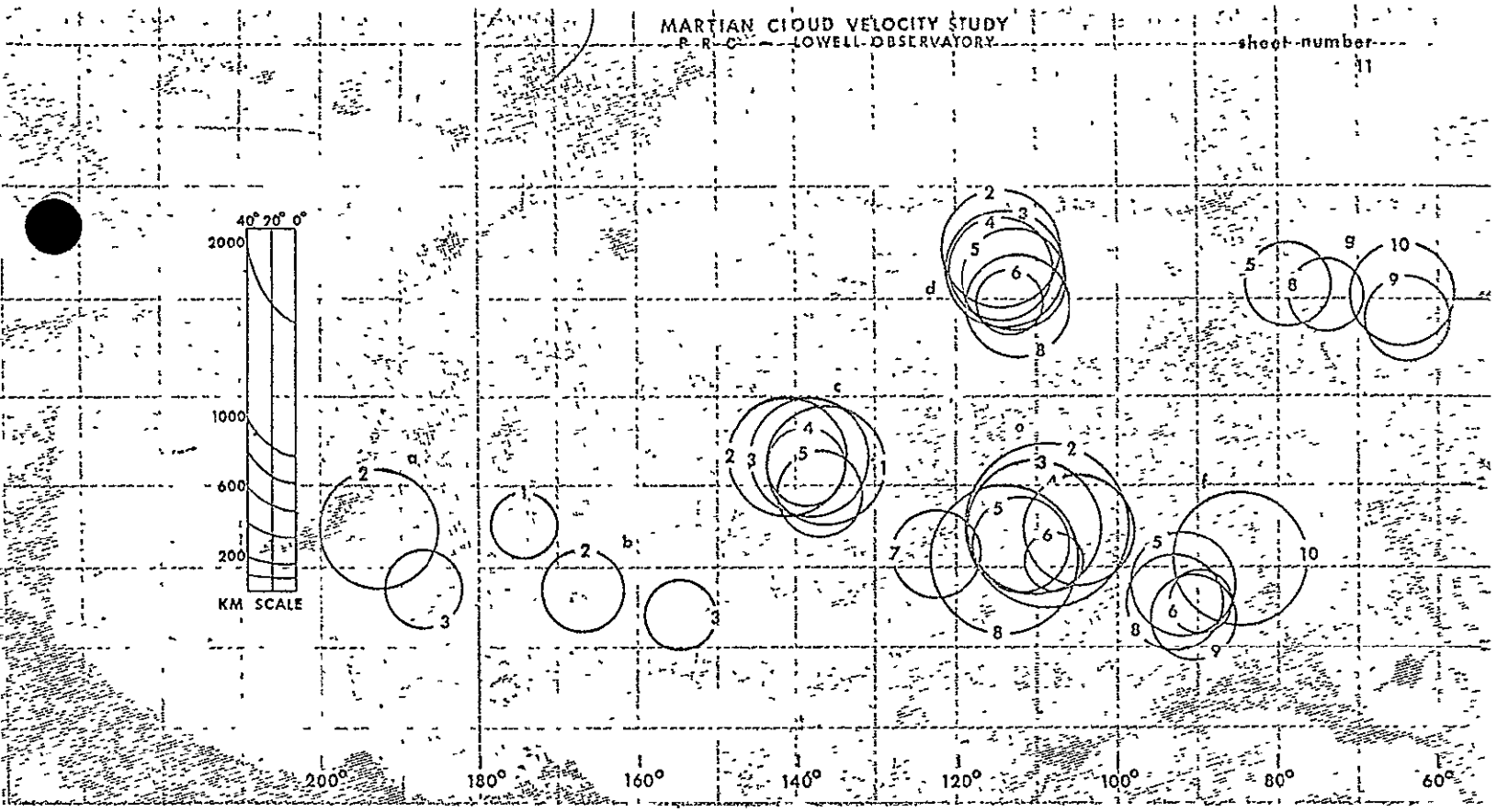


SHEET NO. 10 1935

Dates	Symbols	No. of Plates by Color
23 March	1a	1 blue (not in common)
	1b	2 blue
27 March	2b	1 blue
29 March	3b	1 blue
30 March	4b, 4c, 4d	1 blue
2 April	5a, 5c, 5d	1 blue
7 April	6c	1 blue
10 April	7d	2 blue
11 April	8d	1 blue

NOTES:

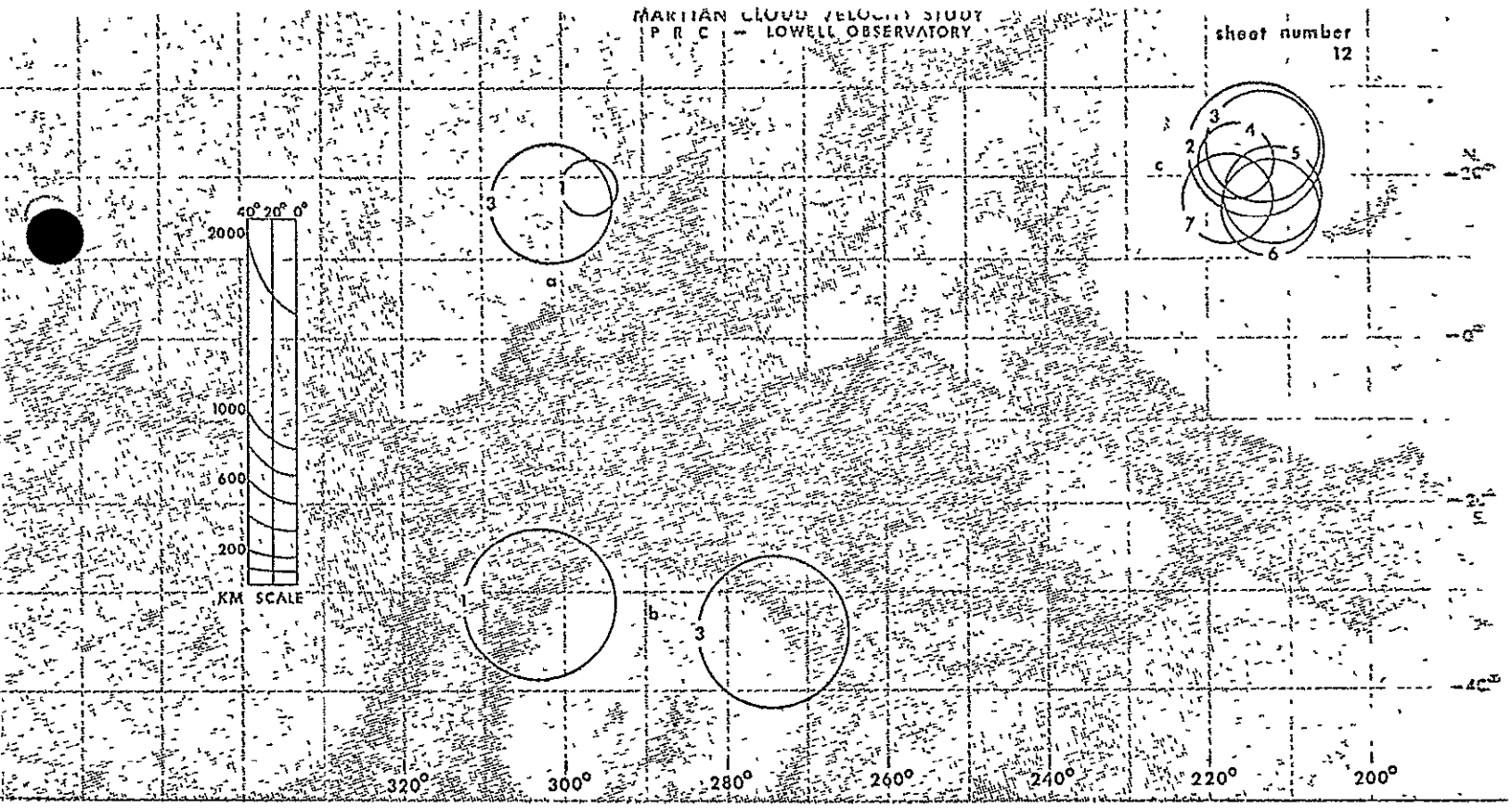
Symbol 7d is the result of averaging two large, nearly circular plots from two different plates. Sheet 11 overlaps Sheet 10 in time and adjoins it to the east.



SHEET NO. 11 1935

Dates	Symbols	No. of Plates by Color
7 April	1b, 1c	1 blue
10 April	2a	1 blue (in common with others)
	2b, 2c, 2d, 2e	3 blue
11 April	3a	1 blue (in common with c,d,e only)
	3b	1 blue (in common with c,d,e only)
	3c	3 blue, 1 yellow (yellow in common with d,e)
	3d, 3e	2 blue, 2 yellow
12 April	4c, 4d, 4e	1 blue
13 April	5c	1 blue, 2 yellow (in common with f)
	5d, 5e	2 blue, 3 yellow
	5f	1 blue, 2 yellow (in common with d,e)
	5g	2 yellow (in common with f)

Dates	Symbols	No. of Plates by Color
14 April	6d, 6e, 6f	1 blue
19 April	7e	1 blue, 1 yellow
20 April	8d	1 blue, 3 yellow (blue, 2 yellow in common with e)
	8e	4 blue, 3 yellow
	8f	2 blue, 3 yellow (2 blue, 2 yellow in common with e)
	8g	1 yellow (in common with d only)
21 April	9f, 9g	1 yellow
23 April	10f, 10g	1 blue, 1 yellow

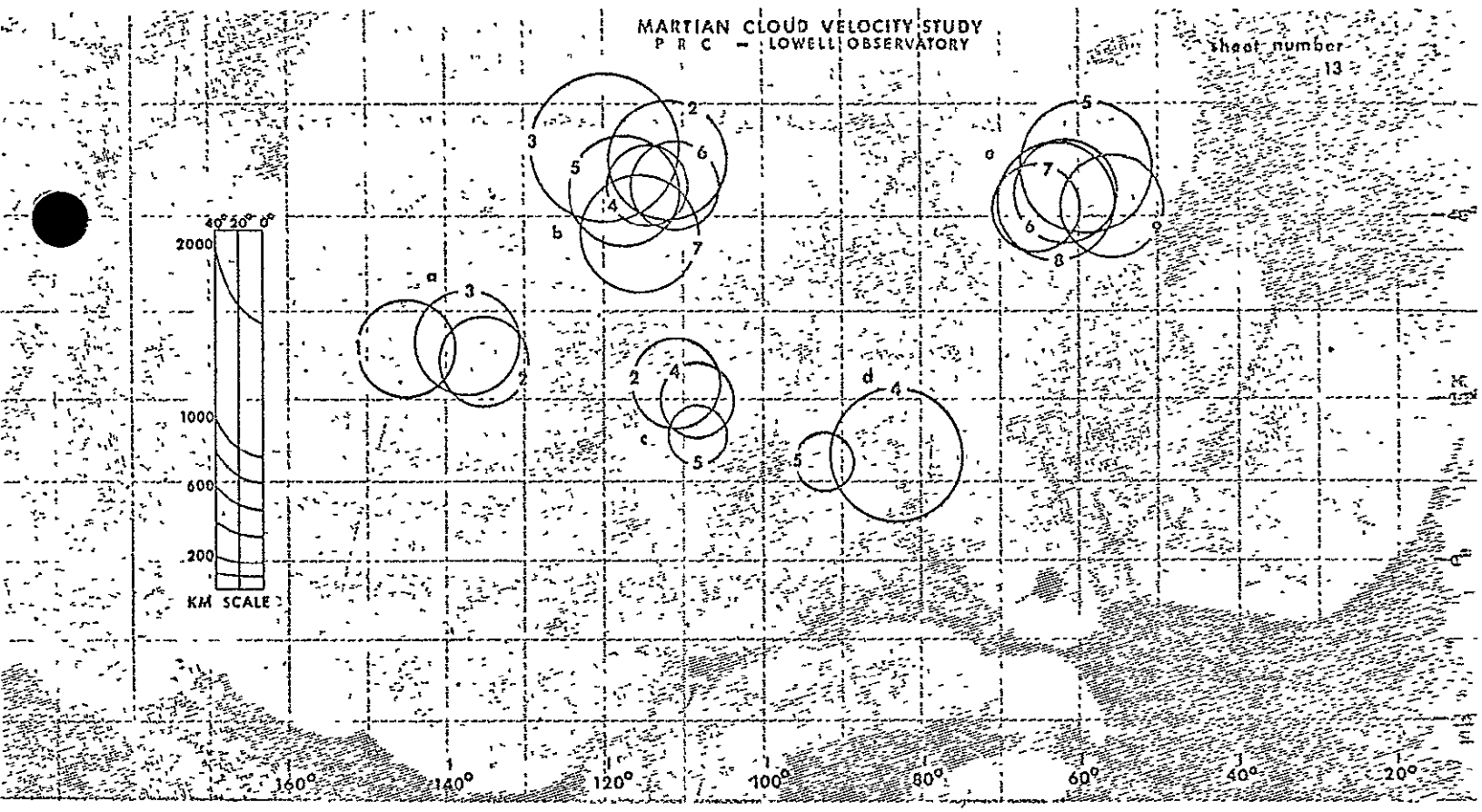


SHEET NO. 12 1935

Dates	Symbols	No. of Plates by Color
27 April	1a, 1b	1 blue
6 May	2c	3 yellow
7 May	3a, 3b	1 blue (in common with c)
	3c	1 blue, 1 yellow
8 May	4c	1 yellow
11 May	5c	1 blue, 1 yellow
14 May	6c	2 blue
16 May	7c	1 blue

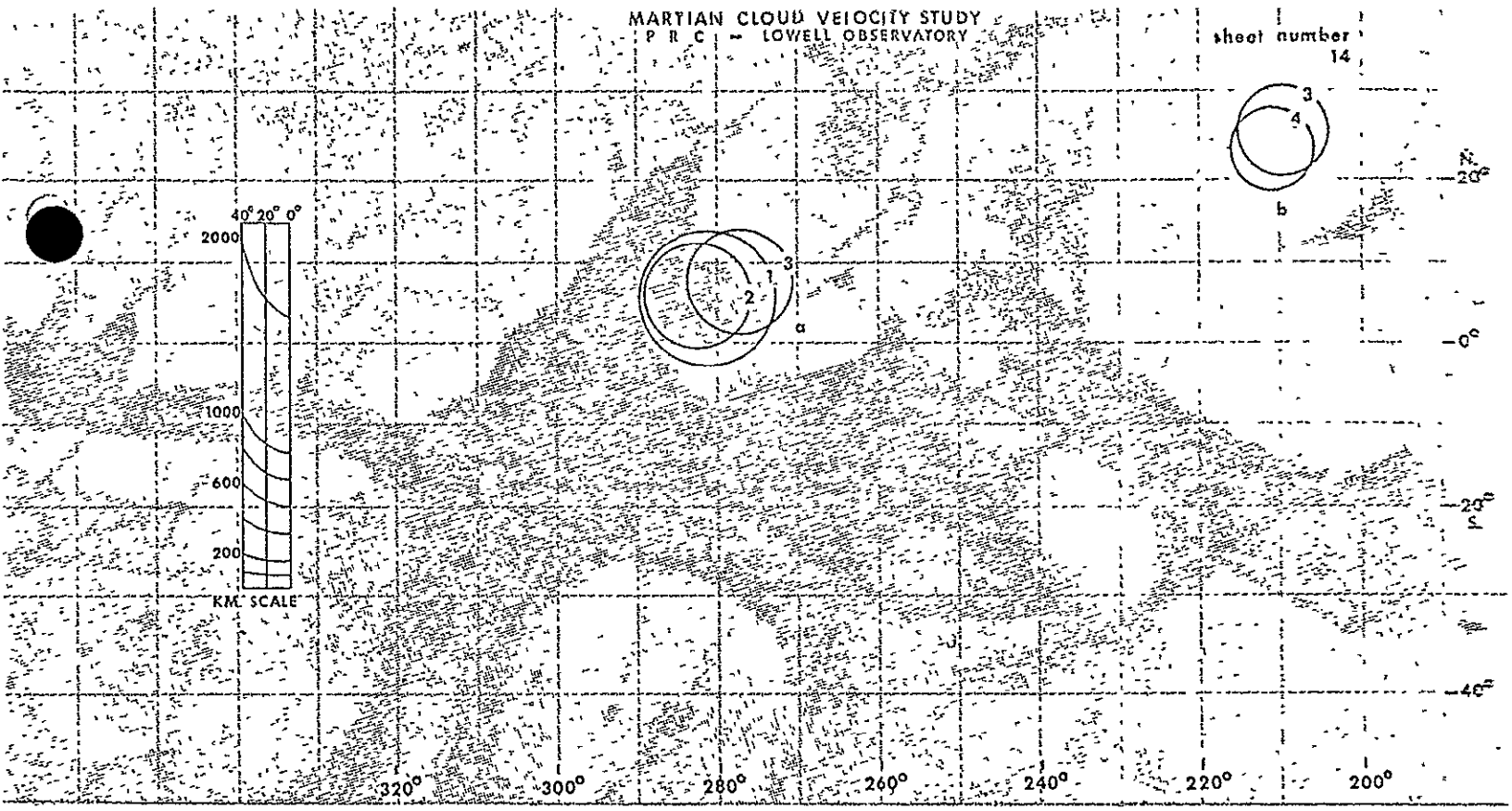
NOTES:

Sheet 12 overlaps Sheet 13 in time and has four plates in common with it.



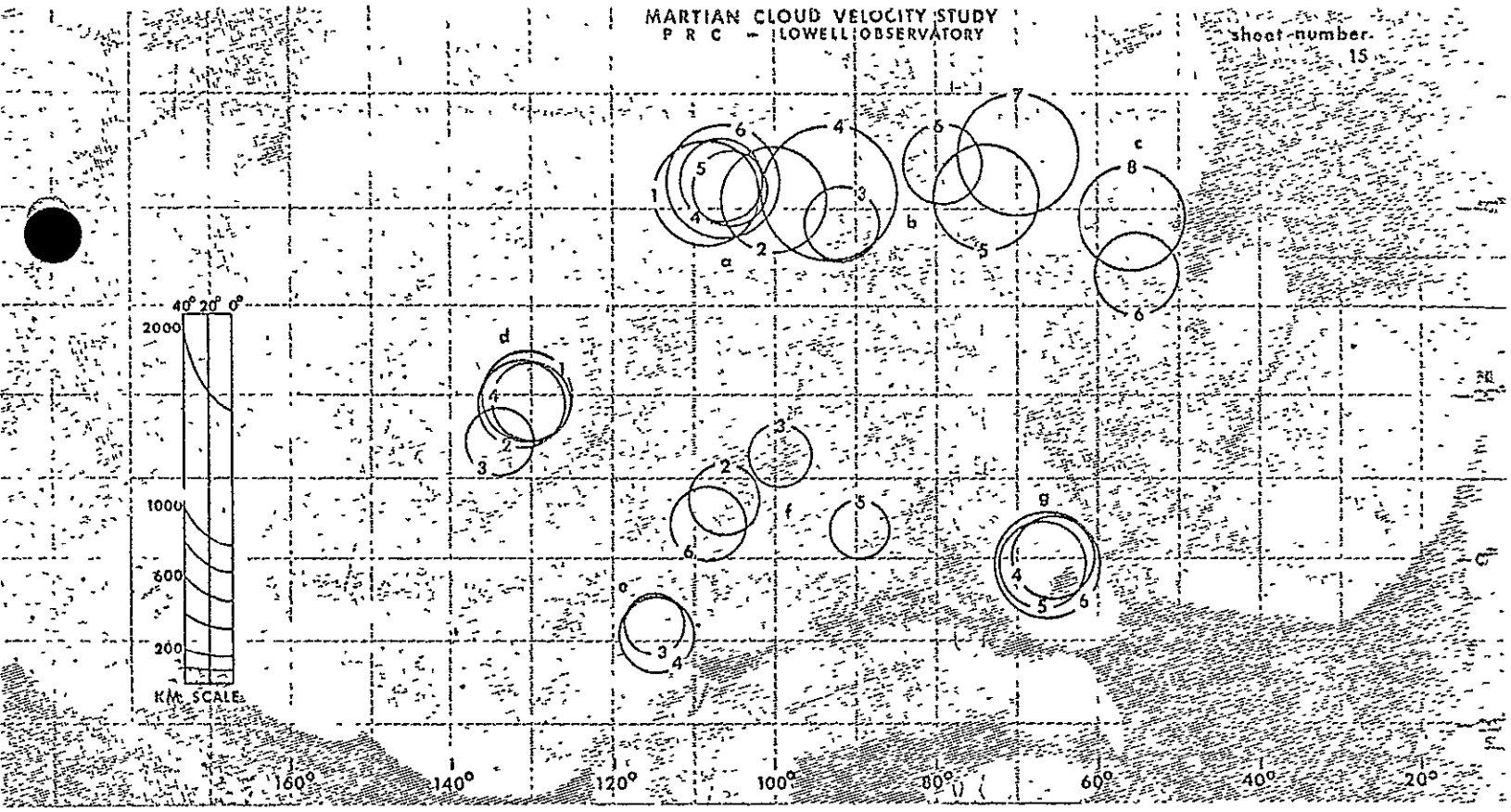
SHEET NO. 13 1935

Dates	Symbols	No. of Plates by Color
11 May	1a	1 blue
14 May	2a, 2b, 2c	2 blue
16 May	3a, 3b	1 blue
22 May	4b, 4c, 4d	1 blue
23 May	5b	1 blue, 1 yellow (in common with e)
	5c	1 blue (in common with b, e)
	5d	1 yellow (in common with b, e)
	5e	1 blue, 1 yellow
24 May	6b, 6e	1 yellow
25 May	7b, 7e	1 yellow
29 May	8e	1 yellow
1 June	9e	2 blue



SHEET NO. 14 1937

Dates	Symbols	No. of Plates by Color
16 April	1a	1 blue
19 April	2a	1 blue
21 April	3a	2 blue (in common with b)
	3b	2 blue, 2 yellow
26 April	4b	1 yellow



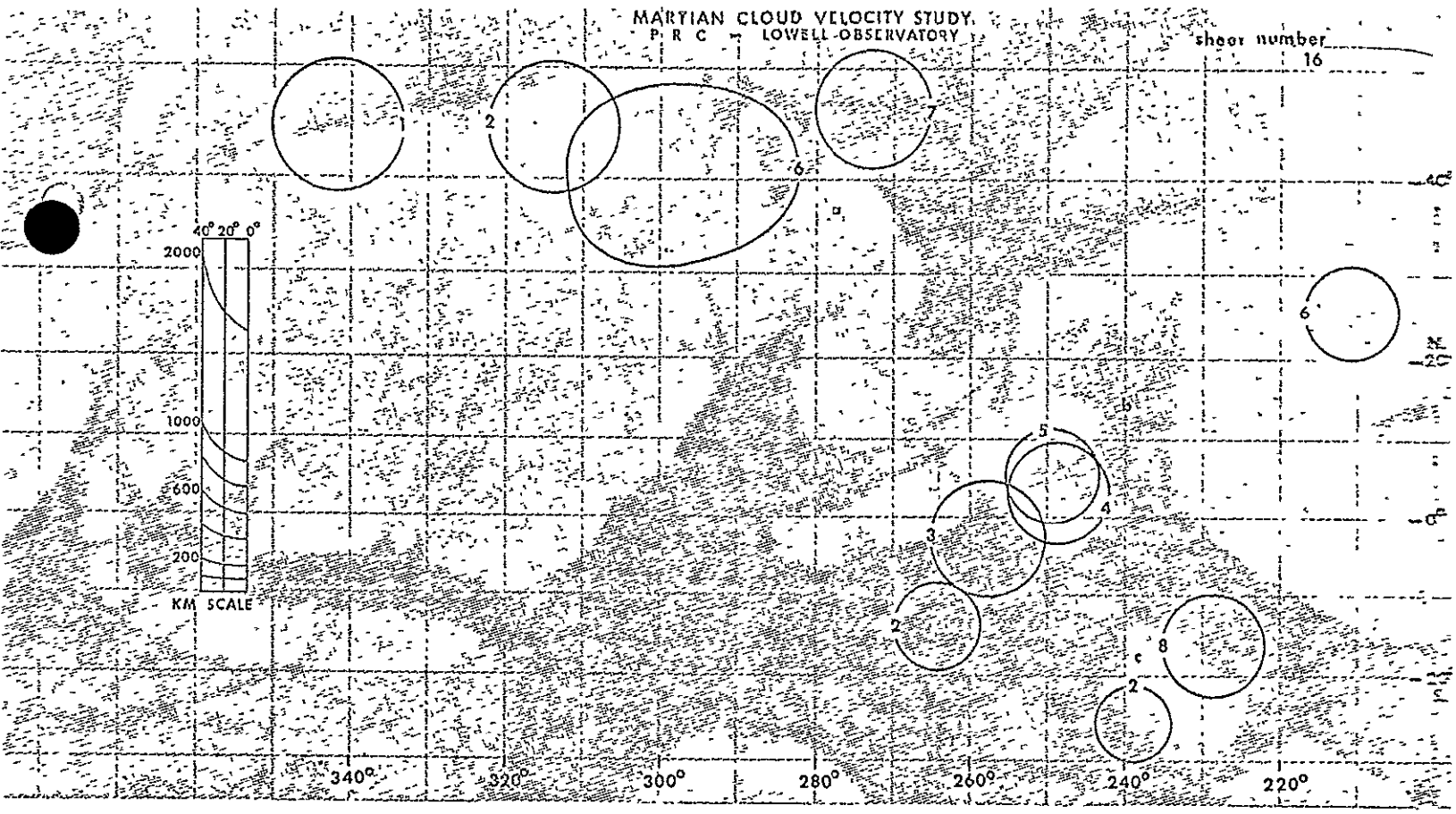
SHEET NO. 15 1937

Dates	Symbols	No. of Plates by Color
29 April	1a	1 blue (in common with d)
	1d	1 blue, 1 yellow
1 May	2a, 2d	1 blue, 1 yellow
	2f	1 blue (in common with a, d)
3 May	3b, 3d, 3e, 3f	1 blue
4 May	4a	1 yellow (in common with g)
	4b, 4d	2 blue
	4e	1 blue (in common with b, d only)
	4g	1 blue, 1 yellow (in common with b, d)
7 May	5a	1 yellow (in common with f)
	5b	1 blue, 1 yellow (in common with g)
	5f	1 yellow (in common with b)
	5g	1 blue, 1 yellow
9 May	6a	1 blue, 2 yellow
	6b	2 yellow (in common with a)
	6c, 6f	1 blue (in common with a, g)
	6g	1 blue, 2 yellow (in common with a)

Dates	Symbols	No. of Plates by Color
14 May	7b	1 blue, 1 yellow
17 May	8c	1 blue, 1 yellow

NOTES:

Symbols 3b and 4b overlap group a, but there are no plates in common. 4b is from blue plates, while 4a is from a yellow plate.

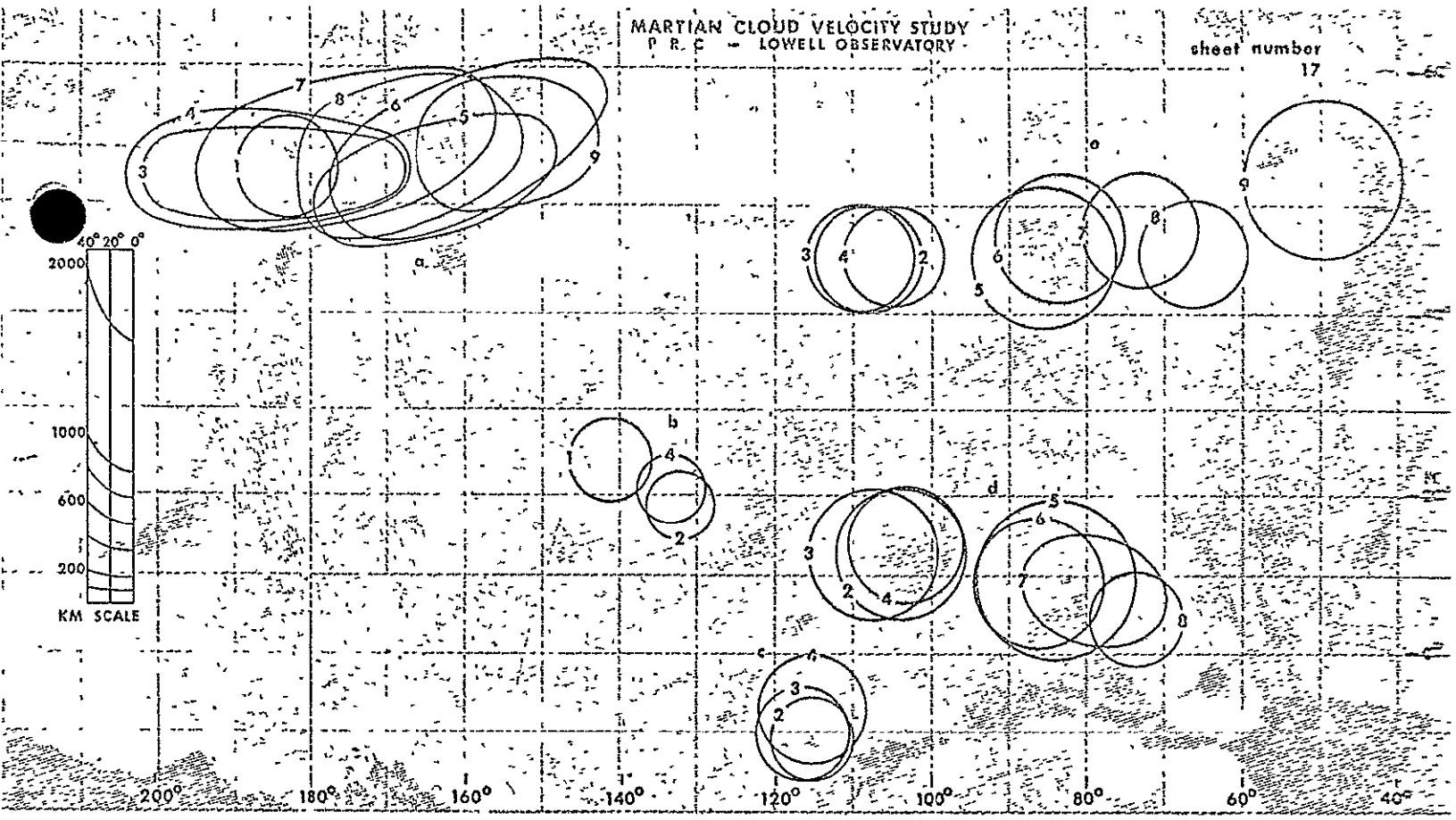


SHEET NO. 16 1937

Dates	Symbols	No. of Plates by Color
14 May	1a	3 blue
21 May	2a	2 blue
	2b	1 blue (in common with a)
	2c	1 blue (not common)
22 May	3b	1 blue
24 May	4b	1 blue
25 May	5b	1 blue
26 May	6a	1 blue (in common with b)
	6b	1 blue, 1 yellow
1 June	7a	1 blue
4 June	8c	1 blue

NOTES:

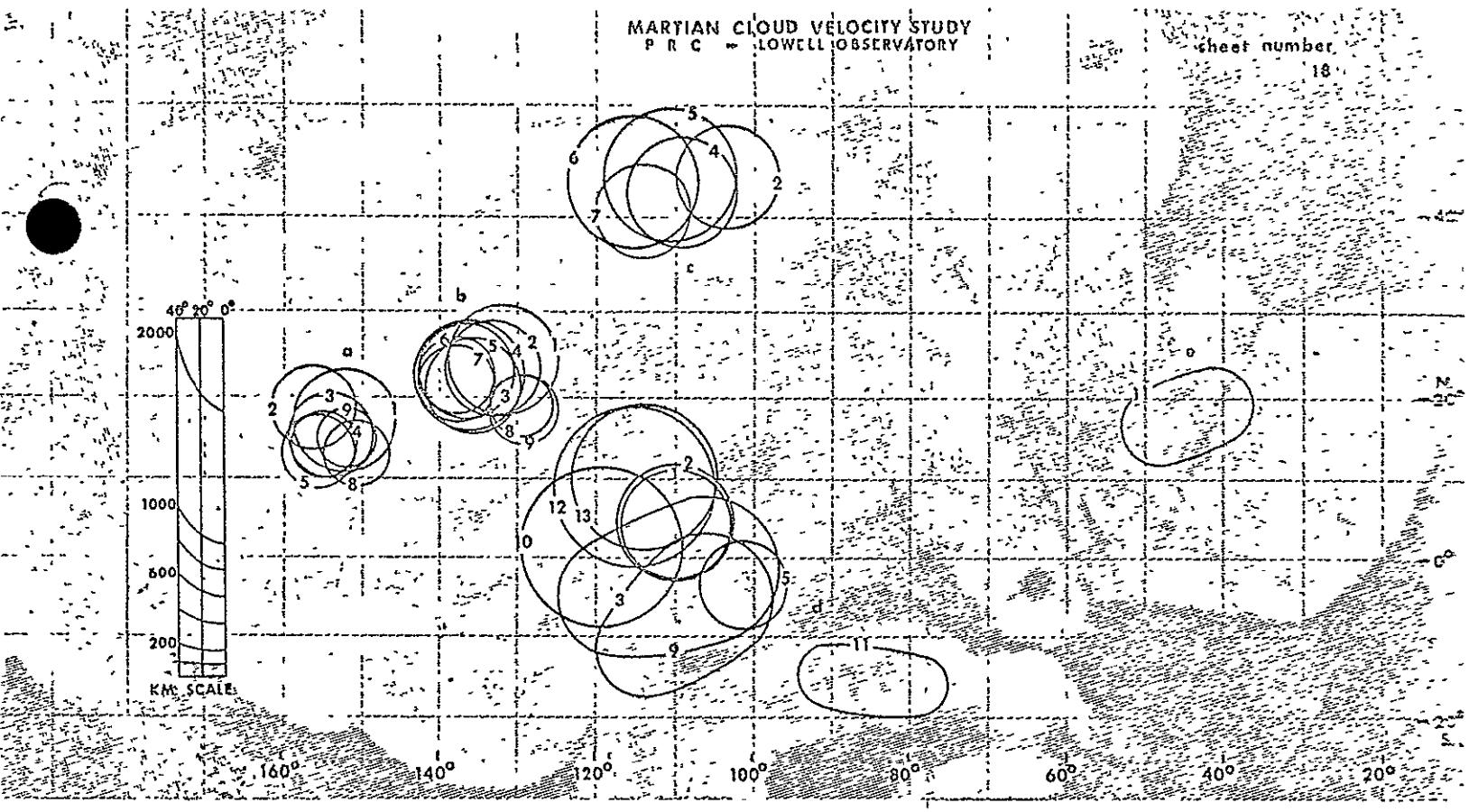
Symbol 6b is over Elysium. Since this area is known for bright spots, it may not be correct to assume it is a progression from the rest of the b group. Sheet 16 overlaps both Sheets 15 and 17 in time and has plates in common with each of them.



SHEET NO. 17 1937

Dates	Symbols	No. of Plates by Color
1 June	1a, 1b	1 blue
2 June	2b	1 blue, 1 yellow
	2c, 2d	1 blue (in common with b, e)
	2e	1 blue, 1 yellow (in common with b)
3 June	3a, 3c, 3d, 3e	2 blue
4 June	4a	1 blue (in common with c)
	4b	1 blue, 1 yellow (in common with d)
	4c	1 blue (in common with b, d)
	4d	1 blue, 1 yellow (in common with e)
	4e	1 yellow, 1 red
5 June	5a, 5d, 5e	3 blue

Dates	Symbols	No. of Plates by Color
7 June	6a	2 blue, 1 yellow
	6d, 6e	1 blue (in common with a)
9 June	7a, 7d, 7e	1 blue
11 June	8a, 8d, 8e	1 blue, 1 yellow
13 June	9a, 9e	2 blue



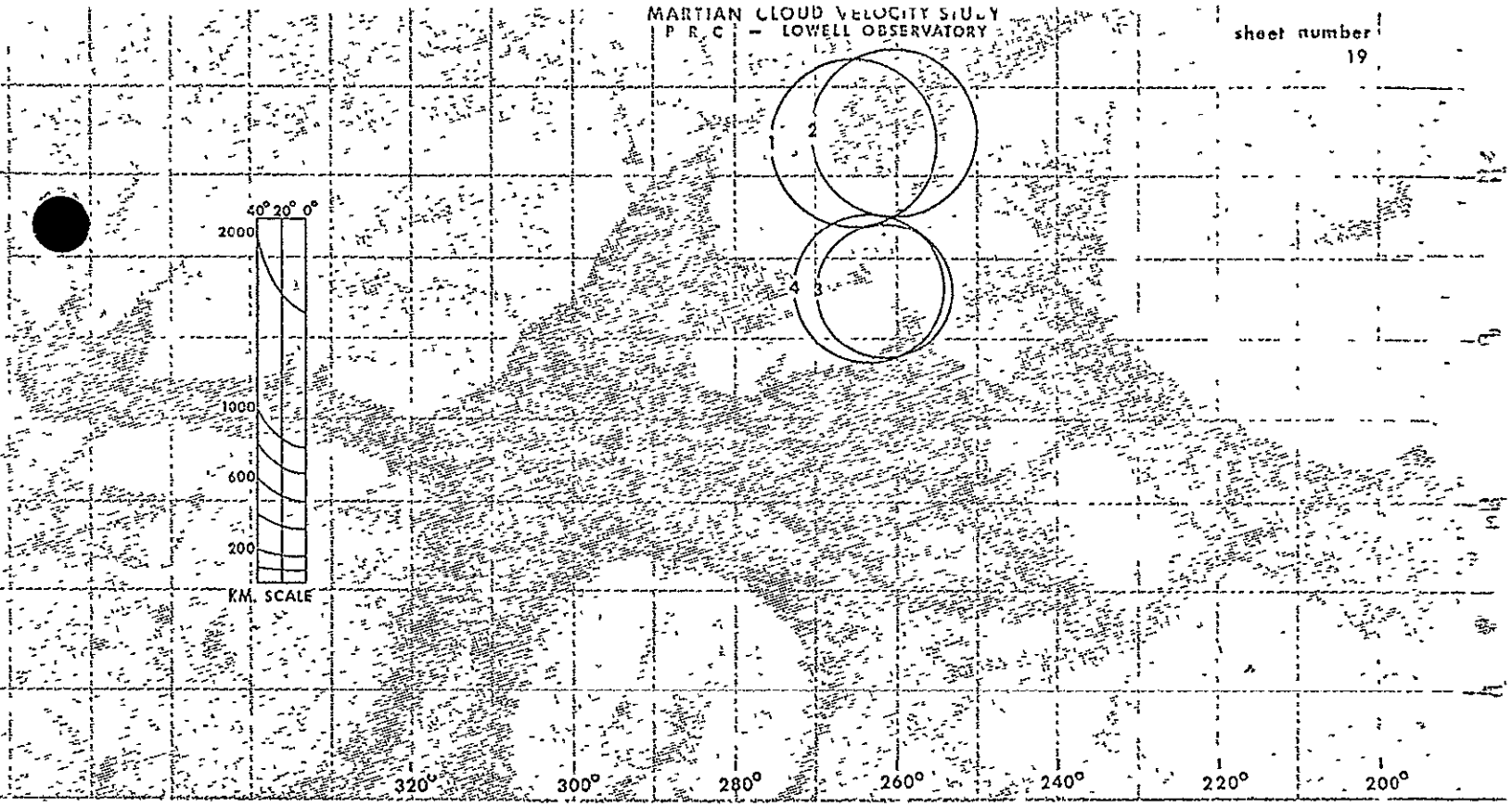
SHEET NO. 18 1939

Dates	Symbols	No. of Plates by Color
18-19 July	1a, 1b	2 yellow, 3 red
	1d	2 yellow (in common with a,b)
19-20 July	2a	2 yellow (in common with b,d)
	2b	3 yellow, 1 red
	2c	1 yellow, 1 red (in common with b)
	2d	2 yellow (in common with a,b)
20-21 July	3a	2 yellow (in common with b)
	3b	5 yellow
	3d	1 yellow (in common with a,b)
21-22 July	4a	1 red (in common with b,c)
	4b, 4c	2 yellow, 2 red
22-23 July	5a	1 yellow, 1 red (in common with b)
	5b	1 yellow, 2 red
	5c	1 yellow, 2 red (reds only in common with b)
	5d	1 blue, 1 yellow (in common with a,b)
23 July	6b	1 yellow (in common with c)
	6c	1 yellow, 1 red

Dates	Symbols	No. of Plates by Color
26 July	7b, 7c	1 yellow
27 July	8a, 8b	1 red
29 July	9a	1 yellow (in common with b,d)
	9b	2 yellow, 1 red
	9d	1 yellow, 1 red (in common with b)
31 July	10d	1 blue
31 July-	11d	2 yellow (in common with e)
1 August	11e	3 yellow, 2 red
1 August	12d	1 blue
6 August	13d	1 blue

NOTES:

Some of the plates used were taken at Lowell Observatory and some in South Africa. The time difference between dates is not uniform since a separate "day-number" has been designated for the plates from each observatory. The plates from Flagstaff are days 8, 9, 10, 12, and 13. All of the others are South Africa. There are only sixteen hours between days 10 and 11, and only five hours between days 11 and 12.

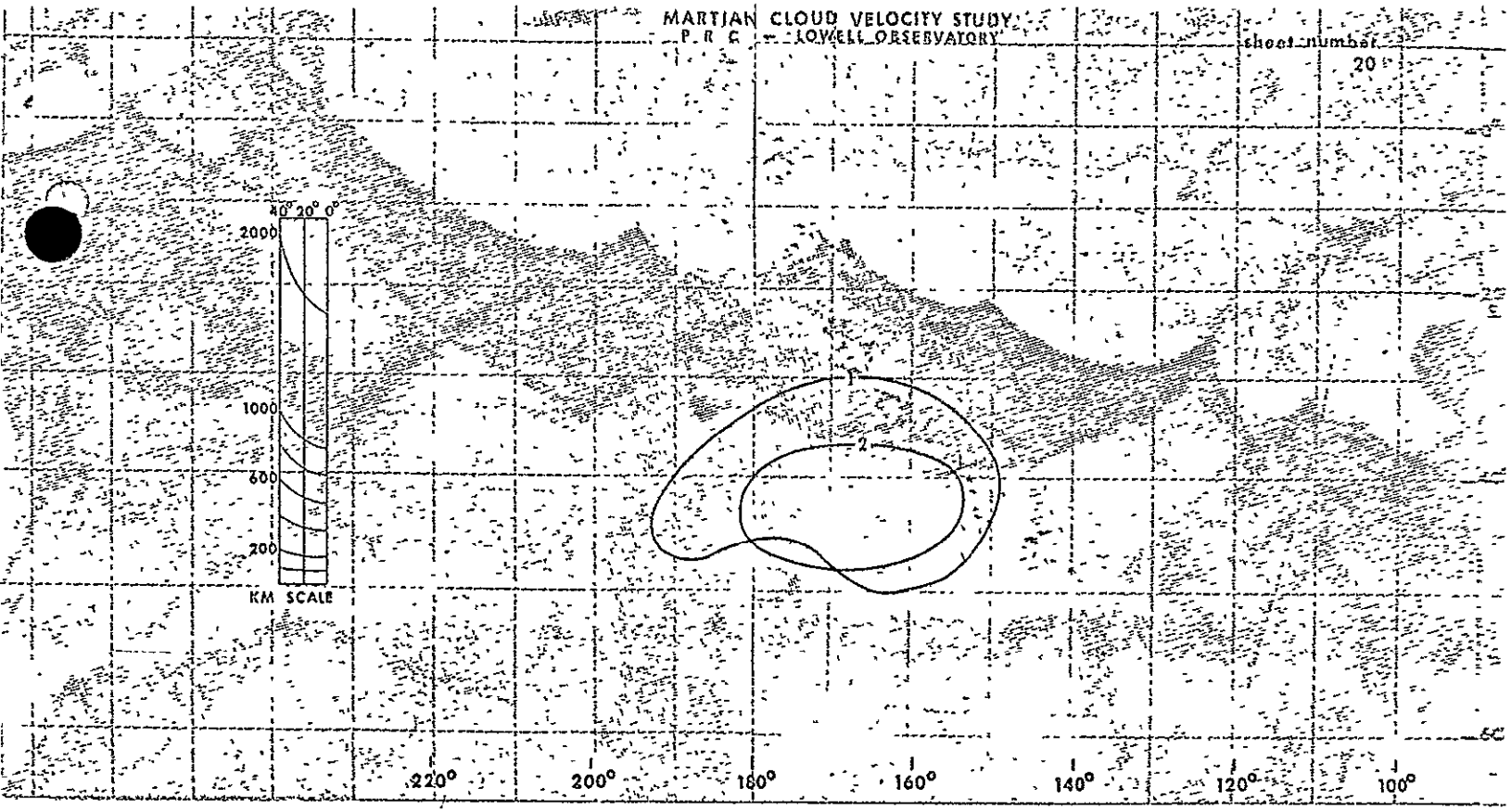


SHEET NO. 19 1939

Dates	Symbols	No. of Plates by Color
19 July	1	1 blue
20 July	2	1 blue
21 July	3	1 blue
22 July	4	1 blue

NOTES:

Sheet 19 falls within the time span of Sheet 18, but no plates are common to both.

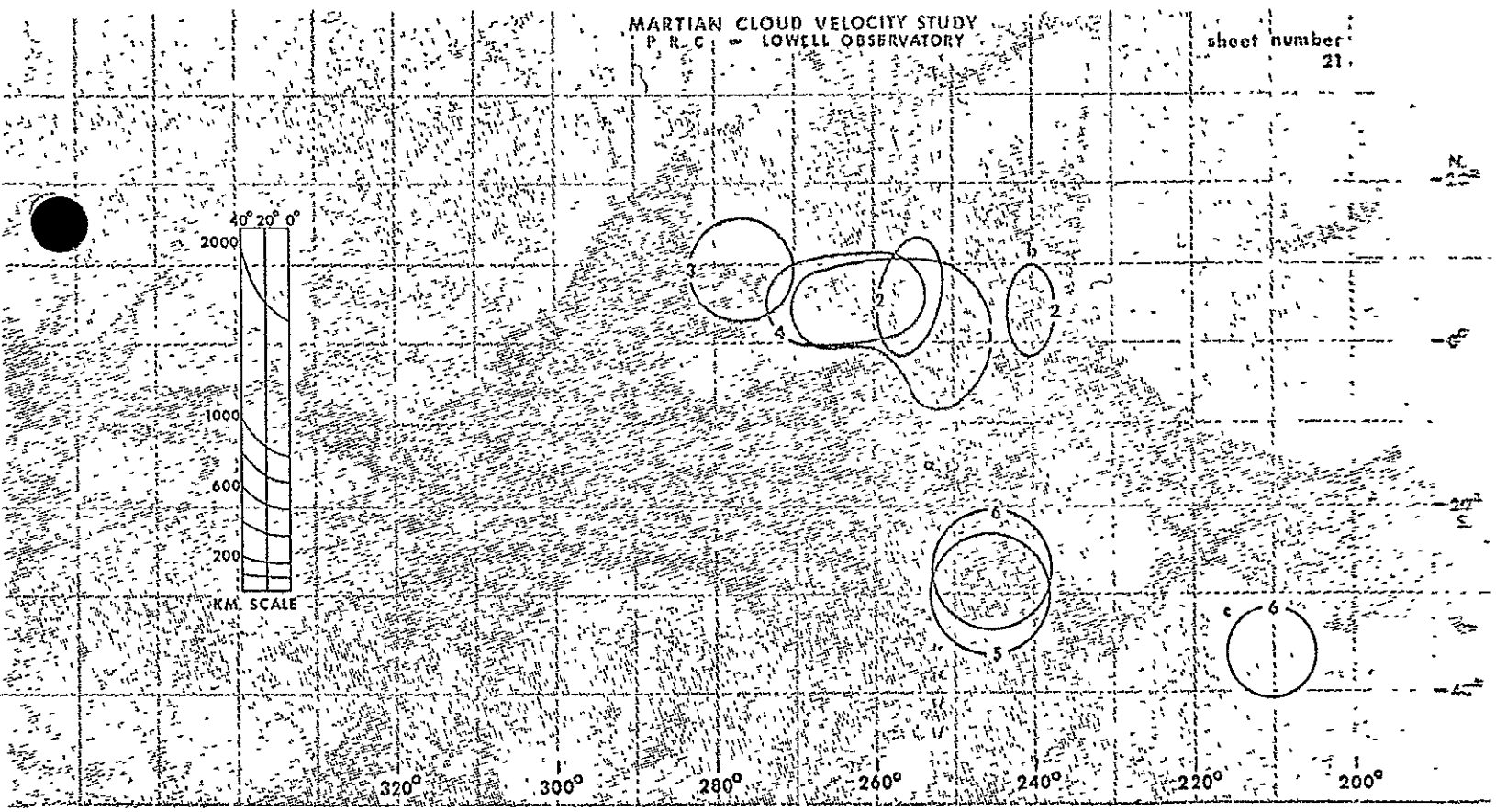


SHEET NO. 20 1941

Dates	Symbols	No. of Plates by Color
23 August	1	2 yellow, 1 red
24 August	2	1 yellow, 1 red

NOTES:

The irregular shapes of the symbols are derived from averaging of the plots from the several plates which were used. These plates are in general agreement, however; and the symbols do reflect the general shapes of the individual plots.

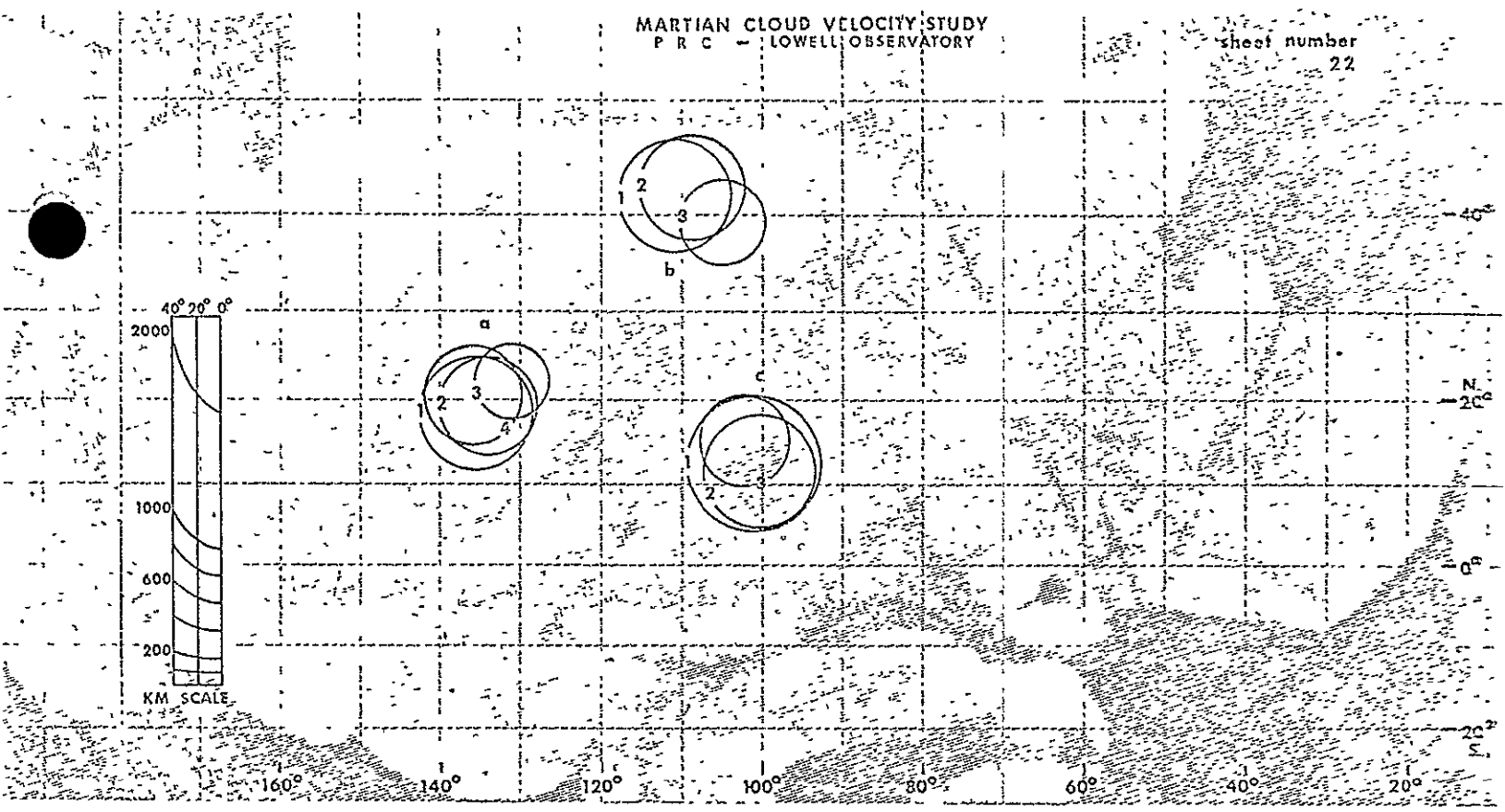


SHEET NO. 21 1943

Dates	Symbol	No. of Plates by Color
28 September	1a	1 yellow
29 September	2a, 2b	1 yellow
3 October	3a	1 yellow
4 October	4a	1 yellow
5 October	5a	1 yellow
7 October	6a	1 yellow (in common with c)
	6c	2 yellow

NOTES:

The three plates used for plotting 3, 4, and 5 were also used by E. C. Slipher on page 119 of his book Mars, The Photographic Story to demonstrate cloud movement. There is a three-day gap to the prior days shown and a one-day gap to day 6, but this wider time span demonstrates the complexity of the situation.

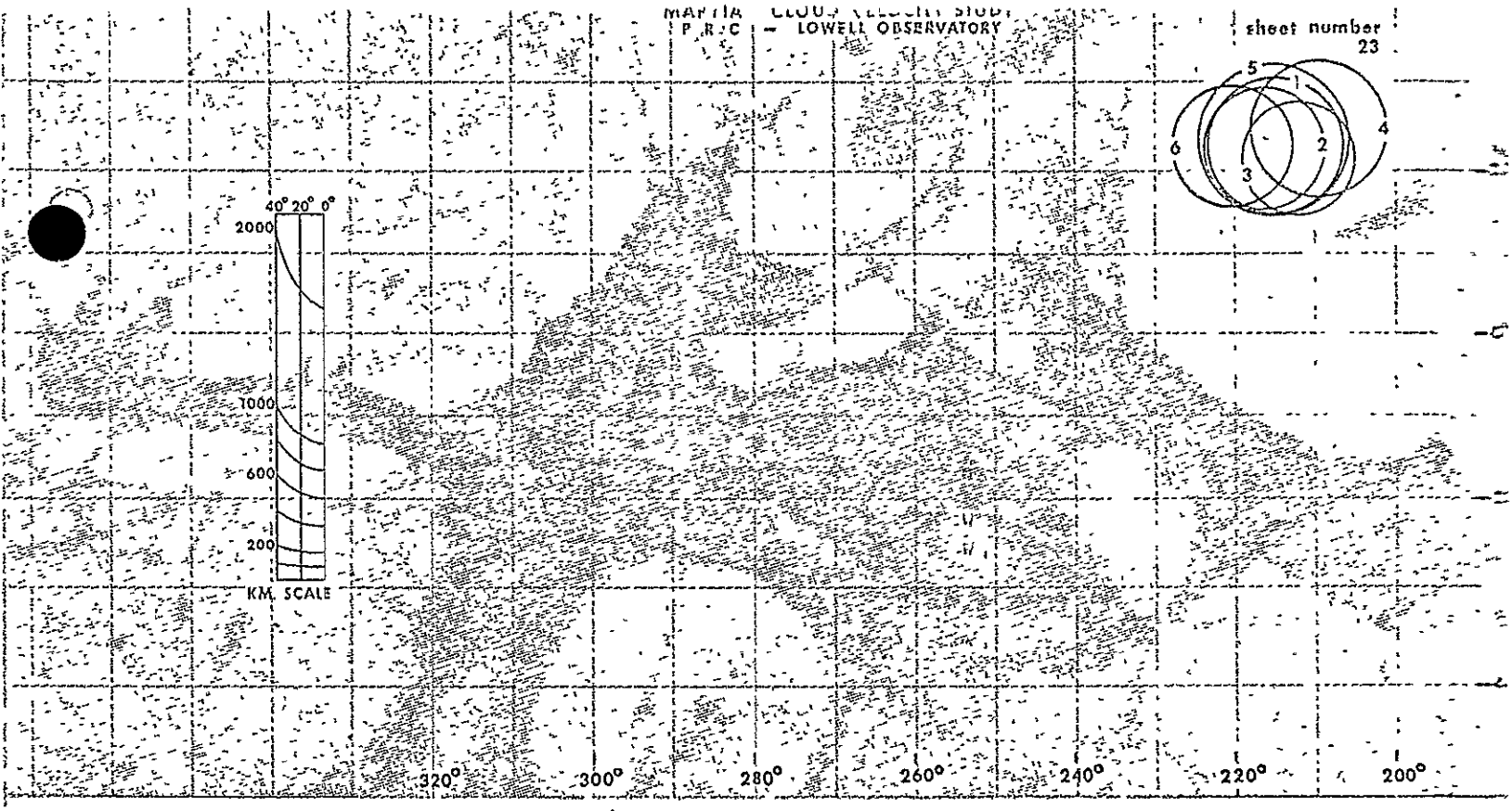


SHEET No. 22 1950

Dates	Symbols	No. of Plates by Color
16 February	1a	2 yellow, 1 green, 1 blue (in common with c)
	1b	3 yellow
	1c	2 yellow, 1 green, 1 blue (in common with b)
17 February	2a, 2b, 2c	1 green, 1 blue
19 February	3a, 3b, 3c	1 yellow
17 March	4a	1 blue

NOTES:

The symbol 4a is from a month later, but was included because of its close fit to the group.



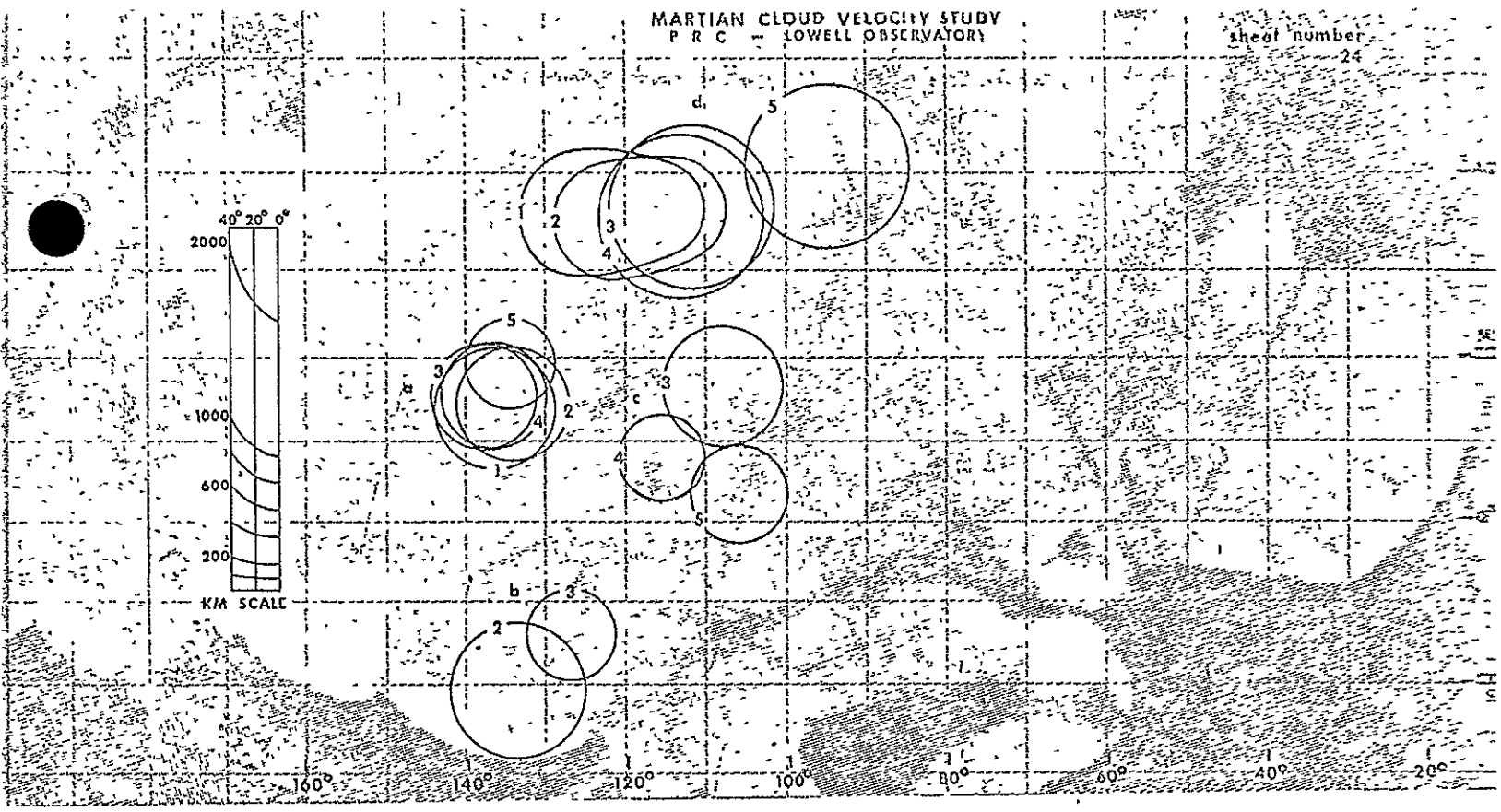
NOT REPRODUCIBLE

SHEET NO. 23

Dates	Symbols	No. of Plates by Color
1 May	1	1 yellow
2 May	2	1 yellow, 2 blue
3 May	3	2 blue
4 May	4	1 blue
5 May	5	1 yellow, 2 blue
6 May	6	1 yellow, 1 blue

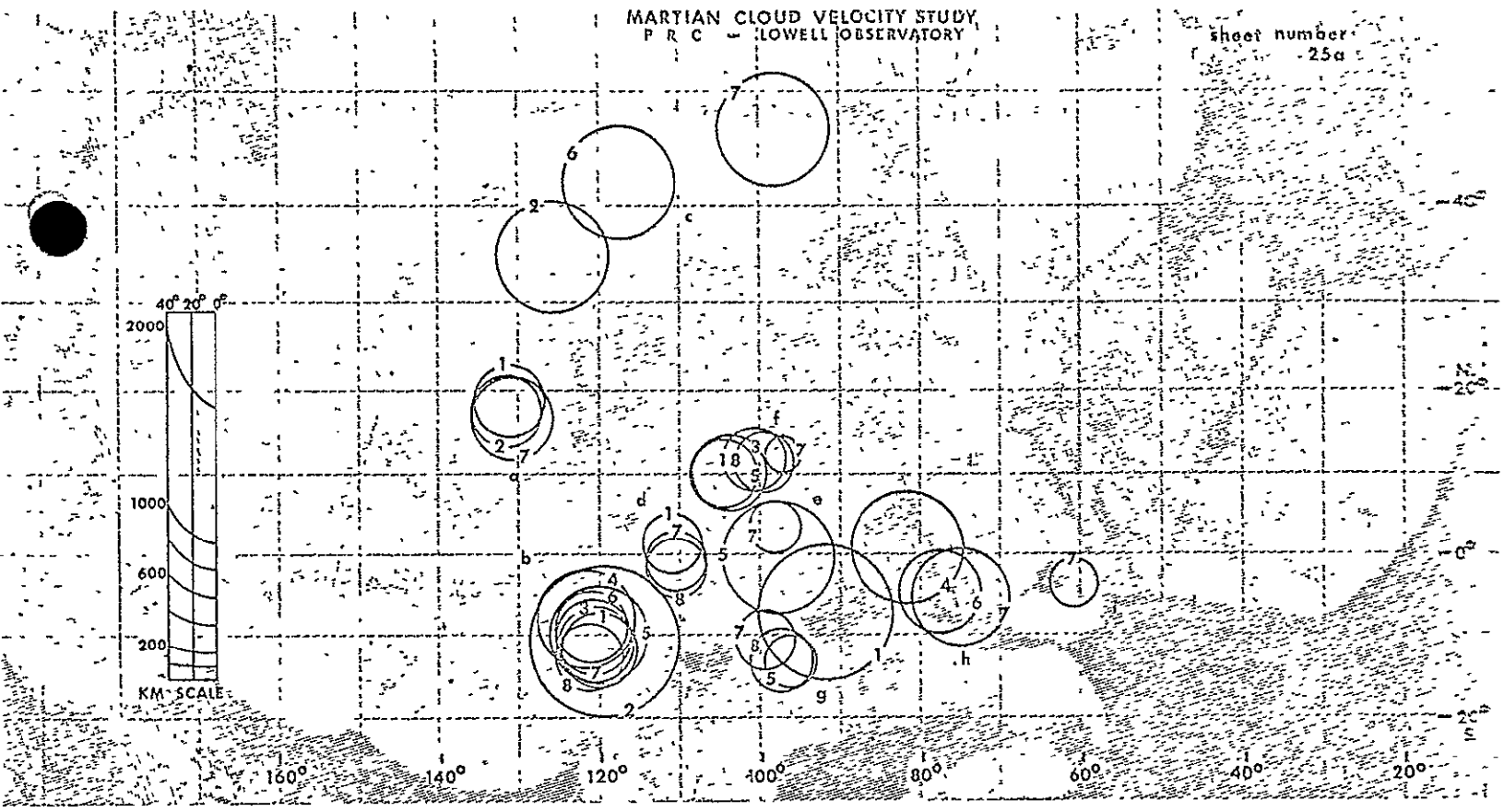
NOTES:

The group of symbols on this sheet is very similar to the one on Sheet 1 (1907).



SHEET NO. 24 1952

Dates	Symbols	No. of Plates by Color
10 May	1a, 1d	1 blue
11 May	2a, 2b, 2d	1 blue
12 May	3a	1 yellow, 2 blue (in common with d)
	3b	1 blue (in common with a, d only)
	3c	1 blue (in common with a, d only)
	3d	1 yellow, 2 blue
13 May	4a	1 blue (in common with d only)
	4c	1 blue (in common with d only)
	4d	2 blue
15 May	5a, 5c, 5d	1 blue



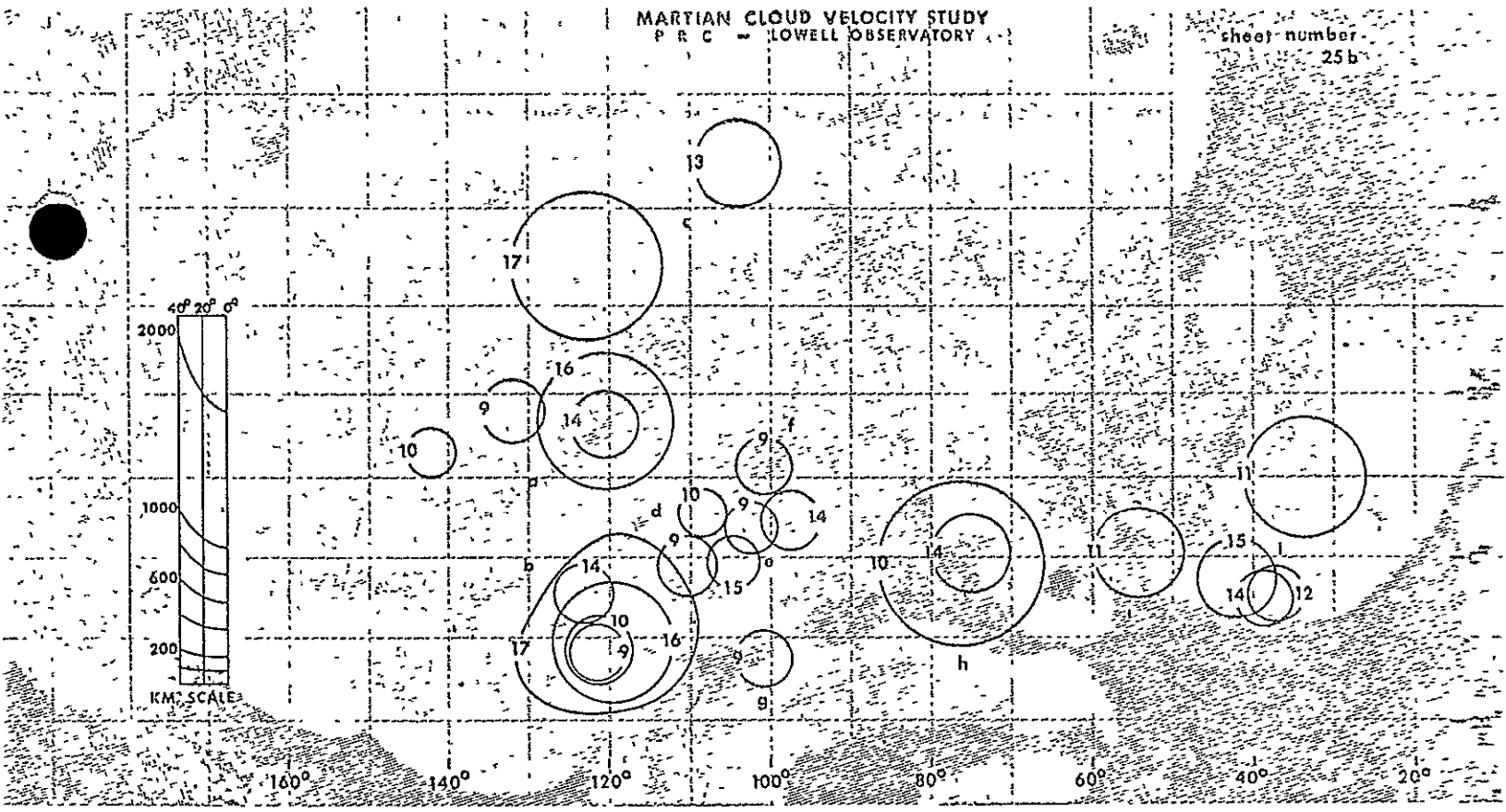
SHEET NO. 25a 1954

Dates	Symbols	No. of Plates by Color
20 June	1a	1 yellow, 1 blue (blue in common with all)
	1b, 1d	2 yellow, 2 blue (in common with a)
	1f, 1g	1 yellow, 2 blue (in common with b,d)
21 June	2a, 2b	1 yellow, 2 blue
	2c	1 yellow, 1 blue (in common with a,b)
22 June	3b	3 blue
	3f	1 blue (in common with b)
23 June	4b	3 blue
	4h	2 blue (in common with b)
24-25 June	5b	3 blue
	5e	2 blue (in common with b)
	5f, 5g	1 blue (in common with b,e)
25-26 June	6b	2 blue
	6c	1 blue (in common with b only)
	6h	1 blue (in common with b only)

Dates	Symbols	No. of Plates by Color
26-27 June	7a	2 yellow, 1 blue (in common with b)
	7b	2 yellow, 2 blue
	7c	1 blue (in common with b,f,g,h only)
	7d	1 yellow (in common with a,b,g only)
	7e	1 blue (in common with h only)
	7f	1 blue (in common with b,c,g,h only)
	7g	1 yellow, 1 blue
	7h	2 blue
	7i	1 yellow (not common to any)
28 June	8b, 8d, 8f, 8g	2 blue
28-29 June	See Sheet 25b.	

NOTES:

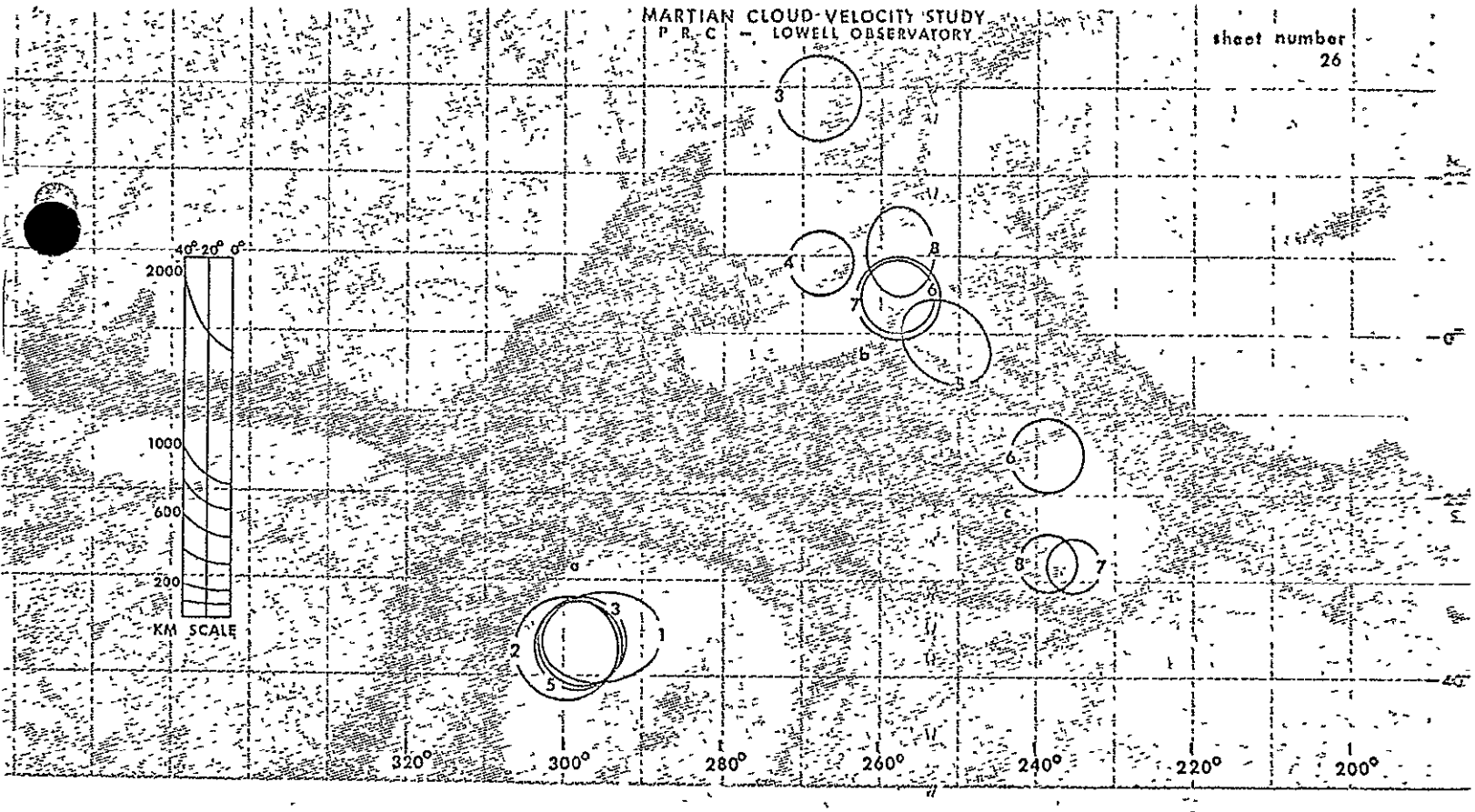
Sheet 25b is a direct continuation of 25a. They were divided into two sheets to avoid congestion of symbols so that they would be legible. The numbering of days continues from one to the next. The designation of groups of symbols by lower-case letters is maintained using the same letters, except that Sheet 25b has no group j.



SHEET NO. 25b 1954

Dates	Symbols	No. of Plates by Color
28-29 June	9a, 9b, 9d	1 blue (in common with f,g)
	9e	2 blue (not common to any)
	9f, 9g	1 blue
29-30 June	10a, 10b, 10d	1 blue (in common with h)
	10h	3 blue
30 June	11i, 11j	1 blue
2 July	12j	2 blue
3-4 July	13c	2 yellow, 1 blue
4-5 July	14a, 14b	1 blue (in common with h,j only)
	14e	1 blue (in common with h only)
	14h	2 blue
	14j	1 blue
5 July	15e, 15j	1 blue

Dates	Symbols	No. of Plates by Color
6 July	16a, 16b	1 yellow
7 July	17b, 17c	1 yellow



SHEET NO. 26

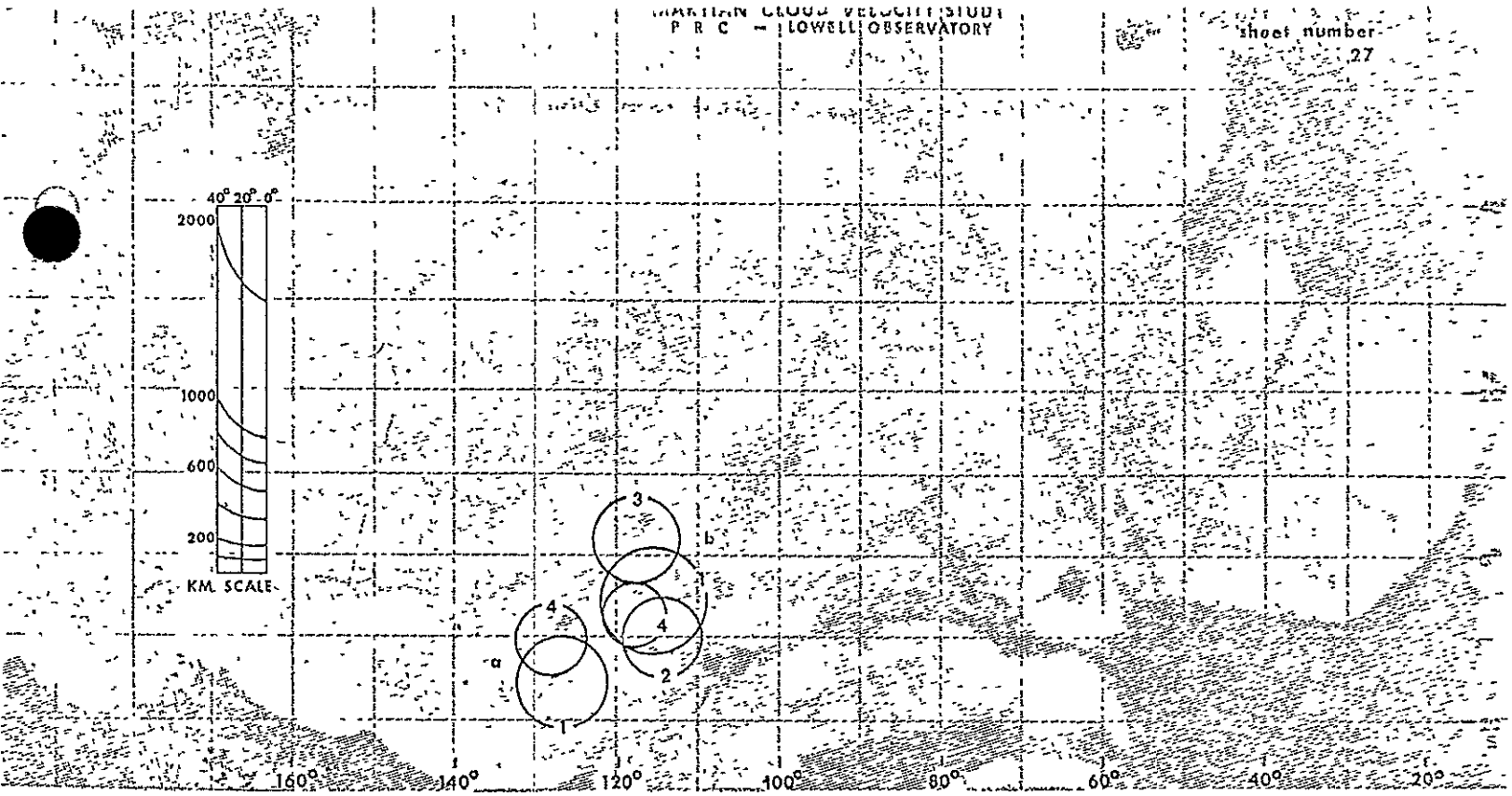
NOT REPRODUCIBLE

1958

Dates	Symbols	No. of Plates by Color
10 October	1a	1 yellow
11 October	2a	3 yellow, 1 red
13 October	3a, 3b	1 yellow, 1 red
14 October	4b	2 yellow
15 October	5a	1 yellow (in common with b)
	5b	1 blue, 2 yellow
16 October	6b, 6c	1 yellow
17 October	7b, 7c	1 yellow
18 October	8b, 8c	1 yellow

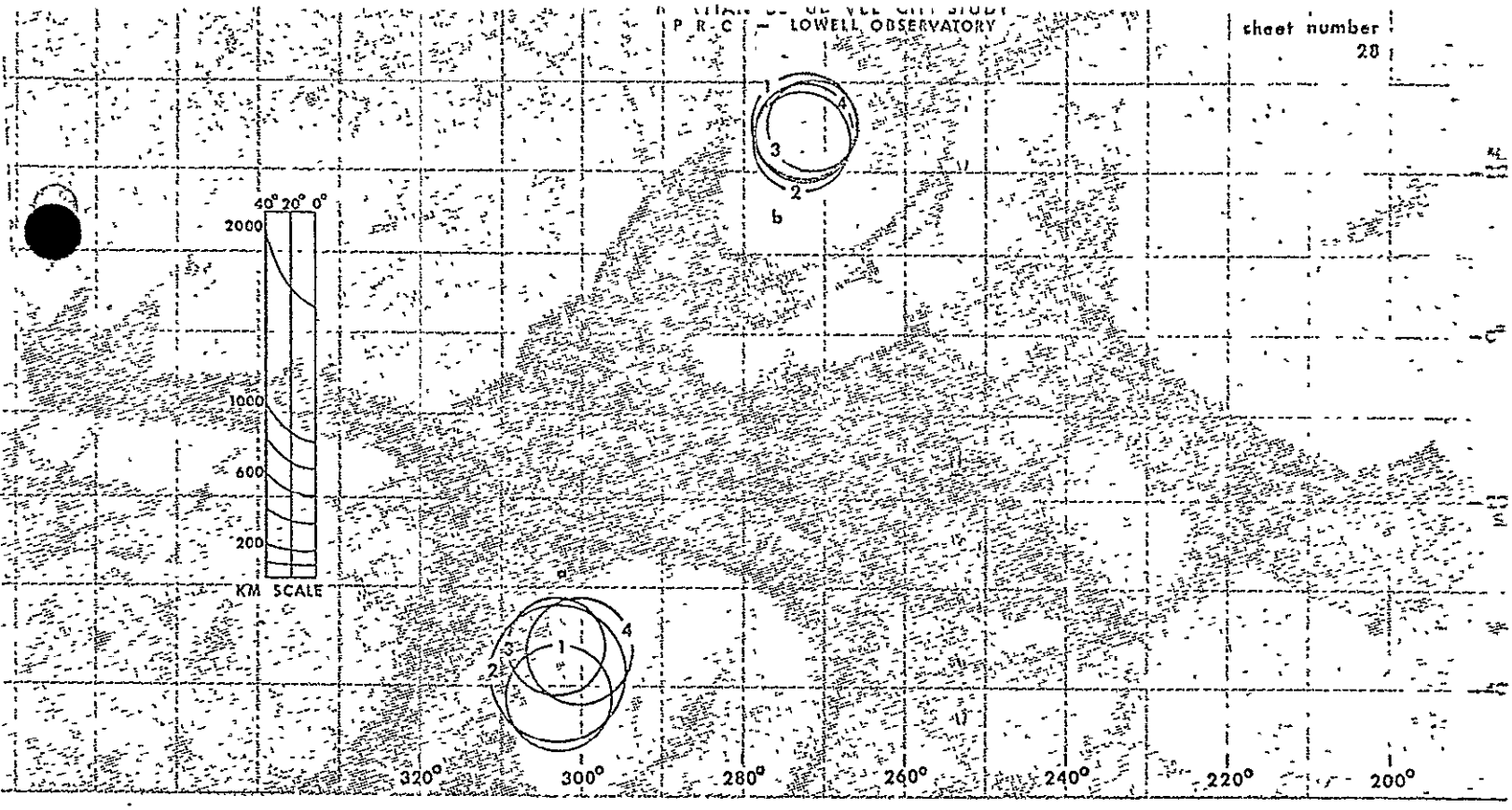
NOTES:

Four of the plates used to plot these symbols were also used by E. C. Slipher to show an example of cloud movement. These are all yellow plates taken on days 3, 4, 5, and 6. He points out movement from 3b to 4b to 5b to 6c. The same plate which he used for 6c also shows something at 6b. The plates taken the next two days bear this out as well as suggest a continued movement from 6c.



SHEET NO. 27 1958

Dates	Symbols	No. of Plates by Color
23 October	1a, 1b	2 blue, 2 yellow
24 October	2b	3 yellow
25 October	3b	1 blue
26 October	4a, 4b	1 blue



SHEET NO. 28 1958

Dates	Symbols	No. of Plates by Color
16 December	1a, 1b	1 yellow, 1 red
19 December	2a, 2b	2 yellow, 1 red
20 December	3a, 3b	1 yellow
21 December	4a, 4b	1 yellow

APPENDIX

A chronological table of plate identifications, with the longitudes of their central meridians (LCM), listing sheet numbers and cloud symbol designations.

PLATE ID	LCM	
M 07 07 11 Y 0334	197	Sheet No. 1, Symbol 1
M 07 07 11 Y 0428	210	Sheet No. 1, Symbol 1
M 07 07 11 Y 0543	228	Sheet No. 1, Symbol 1
M 07 07 12 Y 0333	188	Sheet No. 1, Symbol 2
M 07 07 12 Y 0442	204	Sheet No. 1, Symbol 2
M 07 07 12 Y 0615	224	Sheet No. 1, Symbol 2
M 07 07 12 Y 0621	225	Sheet No. 1, Symbol 2
M 07 07 12 Y 0725	241	Sheet No. 1, Symbol 2
M 07 07 12 Y 0738	244	Sheet No. 1, Symbol 2
M 07 07 12 Y 0825	258	Sheet No. 1, Symbol 2
M 07 07 12 Y 0830	257	Sheet No. 1, Symbol 2
M 07 07 13 Y 0343	180	Sheet No. 1, Symbol 3
M 07 07 13 Y 0453	197	Sheet No. 1, Symbol 3
M 07 07 13 Y 0538	208	Sheet No. 1, Symbol 3
M 07 07 13 Y 0618	217	Sheet No. 1, Symbol 3
M 07 07 13 Y 0656	227	Sheet No. 1, Symbol 3
M 07 07 13 Y 0803	244	Sheet No. 1, Symbol 3
M 07 07 14 Y 0400	176	Sheet No. 1, Symbol 4
M 07 07 14 Y 0623	210	Sheet No. 1, Symbol 4
M 07 07 14 Y 0718	224	Sheet No. 1, Symbol 4
M 07 07 15 Y 0328	161	Sheet No. 1, Symbol 5 Sheet No. 2, Symbol 1a
M 07 07 15 Y 0428	177	Sheet No. 2, Symbol 1a

PLATE ID	LCM	
M 07 07 15 Y 0523	187	Sheet No. 1, Symbol 5 Sheet No. 2, Symbol 1a
M 07 07 15 Y 0738	222	Sheet No. 1, Symbol 5
M 07 07 16 Y 0423	163	Sheet No. 2, Symbol 2c
M 07 07 16 Y 0506	174	Sheet No. 2, Symbol 2a, 2c
M 07 07 16 Y 0543	183	Sheet No. 1, Symbol 6 Sheet No. 2, Symbol 2a, 2c
M 07 07 16 Y 0613	190	Sheet No. 1, Symbol 6 Sheet No. 2, Symbol 2a
M 07 07 16 Y 0708	204	Sheet No. 1, Symbol 6
M 07 07 16 Y 0834	225	Sheet No. 1, Symbol 6 Sheet No. 2, Symbol 2a
M 07 07 17 Y 0238	130	Sheet No. 2, Symbol 3c, 3d
M 07 07 17 Y 0408	152	Sheet No. 2, Symbol 3b, 3c
M 07 07 17 Y 0518	168	Sheet No. 2, Symbol 3a
M 07 07 17 Y 0546	175	Sheet No. 1, Symbol 7 Sheet No. 2, Symbol 3a, 3b
M 07 07 17 Y 0708	195	Sheet No. 1, Symbol 7
M 07 07 17 R 0709	195	Sheet No. 1, Symbol 7
M 07 07 17 Y 0833	215	Sheet No. 1, Symbol 7
M 07 07 18 Y 0055	097	Sheet No. 2, Symbol 4d
M 07 07 18 Y 0148	107	Sheet No. 2, Symbol 4d
M 07 07 18 Y 0648	181	Sheet No. 1, Symbol 8 Sheet No. 2, Symbol 4a
M 07 07 18 Y 0818	202	Sheet No. 1, Symbol 8
M 07 07 19 O 0442	142	Sheet No. 2, Symbol 5b
M 07 07 19 Y 0533	152	Sheet No. 2, Symbol 5b, 5d

PLATE ID	LCM	
M 07 07 19 Y 0640	168	Sheet No. 2, Symbol 5a, 5c
M 07 07 19 Y 0712	175	Sheet No. 2, Symbol 5a, 5c
M 07 07 20 Y 0348	118	Sheet No. 2, Symbol 6d
M 07 07 21 Y 0712	159	Sheet No. 2, Symbol 7a
M 20 04 22 Y 0445	234	Sheet No. 3, Symbol 1f
M 20 04 23 Y 0457	229	Sheet No. 3, Symbol 2b, 2f
M 20 04 23 Y 0832	282	Sheet No. 3, Symbol 2a, 2f
M 20 04 23 Y 0843	284	Sheet No. 3, Symbol 2a
M 20 04 24 Y 0445	218	Sheet No. 3, Symbol 3f
M 20 04 24 Y 0511	224	Sheet No. 3, Symbol 3f
M 20 04 24 Y 0519	226	Sheet No. 3, Symbol 3f
M 20 05 02 Y 0530	159	Sheet No. 4, Symbol 1a, 1b, 1c
M 20 05 04 Y 0545	145	Sheet No. 4, Symbol 2a, 2b, 2c
M 20 05 04 R 0855	192	Sheet No. 3, Symbol 4f Sheet No. 4, Symbol 2a
M 20 05 05 Y 0655	154	Sheet No. 4, Symbol 3a, 3b, 3c
M 20 05 07 Y 0330	086	Sheet No. 4, Symbol 4b, 4d
M 20 05 08 Y 0650	125	Sheet No. 4, Symbol 5b, 5c, 5d
M 20 05 16 Y 0654	056	Sheet No. 4, Symbol 6d
M 20 05 16 Y 0704	058	Sheet No. 4, Symbol 6d
M 20 05 23 Y 0430	319	Sheet No. 3, Symbol 5a
M 20 05 23 Y 0533	334	Sheet No. 3, Symbol 5a
M 20 05 23 Y 0642	350	Sheet No. 3, Symbol 5b
M 20 05 25 Y 0321	283	Sheet No. 3, Symbol 6a

PLATE ID	LCM	
M 20 05 26 Y (1)	276	Sheet No. 3, Symbol 7a, 7d, 7f
M 20 05 27 Y 0405	276	Sheet No. 3, Symbol 8a, 8c, 8d, 8e, 8f
M 20 05 28 Y 0425	271	Sheet No. 3, Symbol 9a, 9c, 9d, 9e, 9f
M 20 05 29 Y 0415	261	Sheet No. 3, Symbol 10b, 10c, 10d, 10f
M 22 07 10 Y 0530	037	Sheet No. 5, Symbol 1
M 22 07 10 Y 0604	046	Sheet No. 5, Symbol 1
M 22 07 11 Y 0503	022	Sheet No. 5, Symbol 2
M 22 07 11 R 0605	037	Sheet No. 5, Symbol 2
M 22 07 11 G 0626	041	Sheet No. 5, Symbol 2
M 22 07 11 G 0643	045	Sheet No. 5, Symbol 2
M 22 07 13 R 0502	003	Sheet No. 5, Symbol 3
M 22 07 13 R 0620	022	Sheet No. 5, Symbol 3
M 24 08 09 Y 0747	262	Sheet No. 6, Symbol 1
M 24 08 09 Y 0809	265	Sheet No. 6, Symbol 1
M 24 08 09 R 0932	287	Sheet No. 6, Symbol 1
M 24 08 10 Y 0640	236	Sheet No. 6, Symbol 2
M 24 08 10 Y 0657	239	Sheet No. 6, Symbol 2
M 24 08 10 Y 0831	263	Sheet No. 6, Symbol 2
M 24 08 10 Y 0900	269	Sheet No. 6, Symbol 2
M 24 08 10 Y 1022	290	Sheet No. 6, Symbol 2
M 26 10 13 B 0730	138	Sheet No. 7, Symbol 1a

PLATE ID	LCM	
M 26 10 13 B 0747	143	Sheet No. 7, Symbol 1a
M 26 10 13 B 0854	159	Sheet No. 7, Symbol 1a
M 26 10 13 B 0913	163	Sheet No. 7, Symbol 1a
M 26 10 13 B 1014	178	Sheet No. 7, Symbol 1a
M 26 10 14 B 0734	131	Sheet No. 7, Symbol 2a
M 26 10 14 B 0758	136	Sheet No. 7, Symbol 2a
M 26 10 14 B 0848	148	Sheet No. 7, Symbol 2a
M 26 10 14 B 0900	151	Sheet No. 7, Symbol 2a
M 26 10 15 B 0614	102	Sheet No. 7, Symbol 3a
M 26 10 18 B 0613	075	Sheet No. 7, Symbol 4d
M 26 10 18 B 0655	085	Sheet No. 7, Symbol 4d
M 26 10 19 B 1045	133	Sheet No. 7, Symbol 5a, 5b, 5c
M 26 10 19 B 1128	143	Sheet No. 7, Symbol 5a, 5b, 5c
M 26 10 21 B 0935	098	Sheet No. 7, Symbol 6a, 6d
M 26 10 21 U 1121	123	Sheet No. 7, Symbol 6a
M 26 10 21 B 1127	126	Sheet No. 7, Symbol 6a, 6b, 6c
M 26 10 23 B 0602	028	Sheet No. 8, Symbol 1a, 1b
M 26 10 26 B 1014	064	Sheet No. 7, Symbol 7d
M 26 10 27 Y 0500	338	Sheet No. 8, Symbol 2a
M 26 10 28 B 0531	337	Sheet No. 8, Symbol 3b
M 26 11 03 B 0248	246	Sheet No. 8, Symbol 4b
M 31 01 31 B 0337	099	Sheet No. 9, Symbol 1b
M 31 01 31 B 0809	164	Sheet No. 9, Symbol 1a

PLATE ID	LCM	
M 31 02 02 B 0444	097	Sheet No. 9, Symbol 2c
M 31 02 09 Y 0325	017	Sheet No. 9, Symbol 3b
M 31 02 09 B 0352	023	Sheet No. 9, Symbol 3b, 3c
M 31 02 09 Y 0457	038	Sheet No. 9, Symbol 3a, 3b
M 31 02 10 Y 0515	035	Sheet No. 9, Symbol 4b
M 31 02 10 Y 0909	092	Sheet No. 9, Symbol 4a, 4b
M 35 03 23 B 0652	336	Sheet No. 10, Symbol 1b
M 35 03 23 B 0827	359	Sheet No. 10, Symbol 1b
M 35 03 23 B 0951	020	Sheet No. 10, Symbol 1a
M 35 03 27 B 0940	342	Sheet No. 10, Symbol 2b
M 35 03 29 B 1216	002	Sheet No. 10, Symbol 3b
M 35 03 30 B 0535	256	Sheet No. 10, Symbol 4b, 4c, 4d
M 35 04 02 B 0842	277	Sheet No. 10, Symbol 5a, 5c, 5d
M 35 04 07 B 0547	189	Sheet No. 10, Symbol 6c Sheet No. 11, Symbol 1b, 1c
M 35 04 10 B 0411	140	Sheet No. 11, Symbol 2a, 2b, 2c, 2d,
M 35 04 10 B 0502	153	Sheet No. 10, Symbol 7d Sheet No. 11, Symbol 2b, 2c, 2d, 2e
M 35 04 10 B 0624	173	Sheet No. 10, Symbol 7d Sheet No. 11, Symbol 2b, 2c, 2d, 2e
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M 35 04 20 Y 0815	113	Sheet No. 11, Symbol 8d, 8g
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